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The naval airship and the revolution at sea

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THE NAVAL AIRSHIP
AND THE REVOLUTION AT SEA

by

James R. Shelby

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Thesis Advisor: Wayne P. Hughes

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A system is proposed to combine an airship based fire control system (using off-the-shelf hardware) with surface ship launched SAMs (NTU/SM-2 ER) to provide OTH wide area ASCM defense for convoys and surface battle groups currently without organic airborne AAW assets. The effectiveness of surface ship AAW area defense is compared, both with and without the airship system, against low-flying ASCMs. The proposed airship system is based on combining the F-14 fire control system (AWG-9) with extrapolations from the current DARPA sponsored design for an operational development model airship (ODM).

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The impact on the required airship size for obtaining a given level of performance from the airship/surface ship team is examined by varying the number of fire control units (AWG-9s) carried by the airship from 2 to 12. Costs of the proposed system are estimated. Scenarios are developed for convoy missions in a low to moderate ASCM threat environment and for surface battle group operations in a high threat (60, closely spaced ASCMs) environment.

Measures of effectiveness for convoy protection are based on variations of achievable Depth-of-Fire by AAW escorts on attacking aircraft and ASCMs. Surface battle group AAW effectiveness is measured by calculation of the "saturation"level of ASCMs required to overwhelm individual "state of the art" AAW escorts. It is shown that using an airship/surface escort based AAW defensive system for convoys will halve the requirement for AAW surface escorts. In the surface battle group scenario it is shown that a combination of airships and older AAW escorts results in, a significant reduction in the total number of AAW escorts required to counter the ASCM threat, reduction in the number of escorts expected to receive damage during a raid, and the attrition of 90% of the attacking tactical aircraft. The cost of obtaining the indicated AAW capability over a 30 year life-cycle is shown to be at least 3 times lower when using an airship based system compared to using a combination of fixed-wing and helicopters.

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THE NAVAL AIRSHIP AND THE REVOLUTION AT SEA

by

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ABSTRACT

A system is proposed to combine an airship based fire control system (using off-the-shelf hardware) with surface ship launched SAMs (NTU/SM-2 ER) to provide OTH wide area ASCM defense for convoys and surface battle groups currently without organic airborne AAW assets. The effectiveness of surface ship AAW area defense is compared, both with and without the airship system, against low-flying ASCMs. The proposed airship system is based on combining the F-14 fire control system (AWG-9) with extrapolations from the current DARPA sponsored design for an operational development model airship (ODM). The impact on the required airship size for obtaining a given level of performance from the airship/surface ship team is examined by varying the number of fire control units (AWG-9s) carried by the airship from 2 to 12. Costs of the proposed system are estimated. Scenarios are developed for convoy missions in a low to moderate ASCM threat environment and for surface battle group operations in a high threat (60, closely spaced ASCMs) environment.

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I. INTRODUCTION

The "*Revolution at Sea*" as envisioned by Vice Admiral Metcalf indicates a radical change in the role, since 1942, of surface warships [Ref. 1]. This changing role is a reflection of the tremendous firepower it is possible to place on a single surface combatant, with the advent of the long range cruise missile. Even in the face of severe budget reductions, many advocates of the "revolution" remain optimistic because of a force wide multiplier effect to be seen by giving a serious offensive role for surface combatant operations, independent of CV Battle Groups [Ref. 2].

The major benefit of having a surface force which would be capable of conducting major operations without carrier or land based air support is the relief given to the existing limited carrier assets. If an adversary has to consider the movements and intentions of several powerful surface action groups in addition to the current carrier centered forces, he would be forced to dilute his forces, perhaps forced to move from an offensive position toward a defensive one, and at the very least, introduce a large measure of uncertainty into the situation.[1] As reported in the December 1988 issue of the *Proceedings of the Naval Institute*, a prominent role for surface combatants was called for in *Surface Combatants Force Requirements Study* (SCFRS), the first "official" naval campaign analysis conducted in a decade. According to the *Proceedings*, SCFRS calls for the independent use of surface forces in two primary arenas, the Surface Action Group (SAG) as described above, and

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[1]This assumes, of course, the tactical wisdom is exercised, not to present the enemy the opportunity to move his combined strength against each force in turn. This also assumes the surface force envisioned can be procured and operated at a lower overall cost than carrier or land based forces.

protection of the shipping [Ref. 3]. Convoy escort or Protection of Shipping (POS), has been the traditional domain of the surface fleet. The assumption is that the carrier forces will be maneuvering to confront the adversary directly and so cannot be spared to guard the maritime logistics supply lines. The most capable "state of the art" surface units will be required in support of carrier operations, leaving vital convoy duty to "low cost" frigates. In SCFRS, the concept of "flexible transition" where older formerly primary anti-air warfare (AAW) escorts, with "upgrades" to extend their useful lives, will move into the convoy escort role. The assumption is made that the threat to shipping will be of a lower order than the threat to CVBGs. The idea of a "flexible transition" is attractive for several reasons. It extends the pay back period over which to recoup the expense of modifying and upgrading the extensive fleet of older AAW cruisers, most of which has already taken place, with installations such as the "New Threat Upgrade" (NTU) package. The second reason the concept is attractive is the increase in the number of hulls dedicated to convoy duties, in the face of the potential damage that might be caused by an underestimate of an adversary's concentration on the supply lines. That is to say, by keeping the pressure on the sea lines of communication, the enemy could force the use of carrier assets in a defensive role, counter to the forward role expressed in "*Maritime Strategy*" [Ref. 4].

Unfortunately for the surface advocates, the birth of the revolution may have been stillborn in December of 1987 when the Secretary of the Navy announced the cancellation of the Naval Airship program, as the first of many austerity measures. This paper demonstrates the central role of organic air surveillance in the realization of the "Revolution at Sea". A system is described for combining airships and AAW escorts for AAW defense. This combination is proposed to have a synergistic effect wherein the strengths inherent in each platform offset the weaknesses of the other. The primary missions for the airship-surface combatant teams are convoy defense and surface action (strike) groups. These missions are

examined to evaluate, in quantifiable terms, the capabilities of surface combatants with and without the proposed airship system.

II. THE AIRSHIP SYSTEM

The airship-based system has as its basis three key concepts and hardware developments.

a. the "sea launched, air targeted" surface-to-air missile

b. the surface AAW tactic "RTLOS"

c. the Operational Development Model airship

These developments are described in the following paragraphs.

In the late 1970s, D.G. Kinney, an analyst in the Office of the Assistant Secretary of Defense (OASD), described extending the already proven use of airships for airborne early warning (AEW) to the role of an airborne fire control system [Ref. 5]. The acronym "SLAT" was coined, by Kinney, for a surface-to-air missile that was "sea launched, air targeted" [Ref. 6]. The use of air-to-air missiles from an airship was also considered. Most significant to this analysis was the near unconstrained supply of missiles in the SAM firing surface ship. The concept of an airship-based fire control system was endorsed by the unlikely source of the Soviet Navy. In a 1980 paper, two Soviet officers made a favorable assessment for the survivability of a U.S. Carrier Battle Group (CVBG) when aided by a proposed five airship squadron equipped with the AWG-9 fire control system and the Phoenix air-to-air missile [Ref. 7].

The pivotal concept has been the development of the use of one surface AAW escort to relay air search radar data via the "Link 11" tactical data link (NTDS) to another surface AAW escort which, in turn, uses the remote radar data to launch and guide a SAM into terminal homing. The capability is known as "Remote Targeted, Launch on Search" (RTLOS) and has been operationally demonstrated [Ref. 8]. An extension of RTLOS allows

for a missile to be fired by one AAW escort based on the search radar data from the tactical data link with the difference that final control of the SAM is "passed" or transferred from the launching ship to the ship providing the remote data link input. The remote ship then takes control of the SAM, as though the SAM had been launched from the remote ship. It is the this extension of RTLOS that provides the SLAT capability to the airship system.[Ref. 9]

The last major development occurred in 1987 when, as the result of a competitive bid, Westinghouse-Airship Industries (WAI) was awarded a $169 million dollar contract to build and test a 2.3 million cubic foot (mcf) displacement prototype Battle Group Surveillance airship [Ref. 10]. The combat system of the airship was to be based on components from existing naval aircraft.[1]

As a developmental vehicle, the prototype was to demonstrate the following:

a. operate at 10,000 ft

b. achieve a dash speed of near 90 knots

c. validate the concept of a 96 hour replenishment cycle

d. operate as an organic asset to a Surface Battle Group for a period of not less than 30 days without external (from the battle group) support

e. accomplish the above without excessive demands on existing battle group assets

The airship system proposed in this analysis is based on projecting the current WAI development program to cover a vehicle which has sufficient lift to support a surface-to-air

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[1]As originally conceived, the ODM was to be based on the E2-C combat suite, however WAI later proposed an alternative avionics suite (for payload weight and cost savings)from the S3-B "Viking" carrier based ASW aircraft, combined with the TPS-63 air search radar. The Westinghouse TPS-63 radar was developed for U.S.M.C. requirements and has been in use for a number of years in aerostat applications. It is the "alternative" combat system upon which this paper is based.

missile fire control system. The fire control system is to be developed from off-the-shelf hardware by integrating AWG-9 fire control units, NTU hardware and the avionics suite from the ODM airship.[2] The resulting combat system would provide a SLAT capability between the airship and a suitably modified NTU AAW escort.

A. FIRE CONTROL SYSTEM PERFORMANCE

The most difficult level of performance to judge is not that of the airship, but that of a fire control system which can be installed in a given airship design.[3] For the purpose of analysis, the level of performance desired from the airship fire control system will be the ability to conduct 12 simultaneous engagements. This level of performance does not imply the airship would necessarily support 12 targets in terminal homing simultaneously, but that the system has the ability to have surface-to-air missiles airborne against 12 targets. Given the state of the art in modern AAW escorts, this level of performance for the airship/AAW escort team is considered moderate.

Rather than conduct a sensitivity analysis around the 12 engagement figure to determine the impact of failing to obtain the desired performance level, the airship combat system will be varied across a range of complexity to gauge the impact of achieving the desired performance level on the airship design. The combat system will start with a low level of inherent capability, with the complexity of the system (and weight) increasing. This goal is accomplished by initially sizing the airship with a base line avionics suite, as intended for the

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[2]The first two to four AWG-9 units would be mounted on the roof of the control car. Additional units would be suspended internally from the envelope. Envelope mounting of radars on airships was demonstrated on the ZPG-3W series airships.

[3]A large body of literature is available on the actual and theoretical characteristics of airships. For the interested reader, the Reference List cites numerous sources on the history of airships, the engineering and physical principles involved in buoyant flight.

ODM, with the addition of NTU hardware, a JTIDS data link and 2 AWG-9 fire control systems. To enhance the system capability, the number of AWG-9 units is increased with an attendant increase in airship displacement. From it's characteristics, the Hughes AWG-9 fire control system is readily adaptable for work with the NTU variants of the Standard missile family [Ref. 11:sec. 3.5.2]. Given that one AWG-9 system can support at least one engagement, the requirement to support 12 engagements is assured at the extreme position of including 12 AWG-9 systems on the airship. With such a large number of fire control radars in close proximity, management of electromagnetic interference (EMI) becomes a critical requirement.

1. Track Management

The airship fire control system is illustrated in Figure 1. Target detection and tracking is accomplished primarily with the aid of the Westinghouse TPS-63 air search radar and tracking system. However, inputs for track management are taken from the installed AWG-9 units operating in an air search or Track-While-Scan mode. When the airship's air search radar detects a new target the information is passed to the Target Tracker and the NTU fire control computer [Ref. 12]. The NTU fire control computer assigns the earliest available AWG-9 fire control unit to assist the TPS-63 search radar in establishing a "track" on the newly detected target and relays the detection and a standby to engage order to the data linked surface AAW escort.[4][Ref. 13] If a AWG-9 unit is available, it will pass data on the new target to the Tracker in conjuction with the TPS-63 with the objective of reducing the time taken to establish the track and begin the engagement phase. If an AWG-9 unit is not

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[4]The track is established when the Kalman filter algorithm has received enough data to make accurate predictions of the future position of the new target. The filter process starts at target detection and a prediction of where the target should be on the next scan is made based on the update from the previous scans of the search radar, with the prediction improving with additional scans. When a predetermined number (m out n) of the filter's predictions of the targets future position "match" the position found on succeeding search radar scans, the track is established.

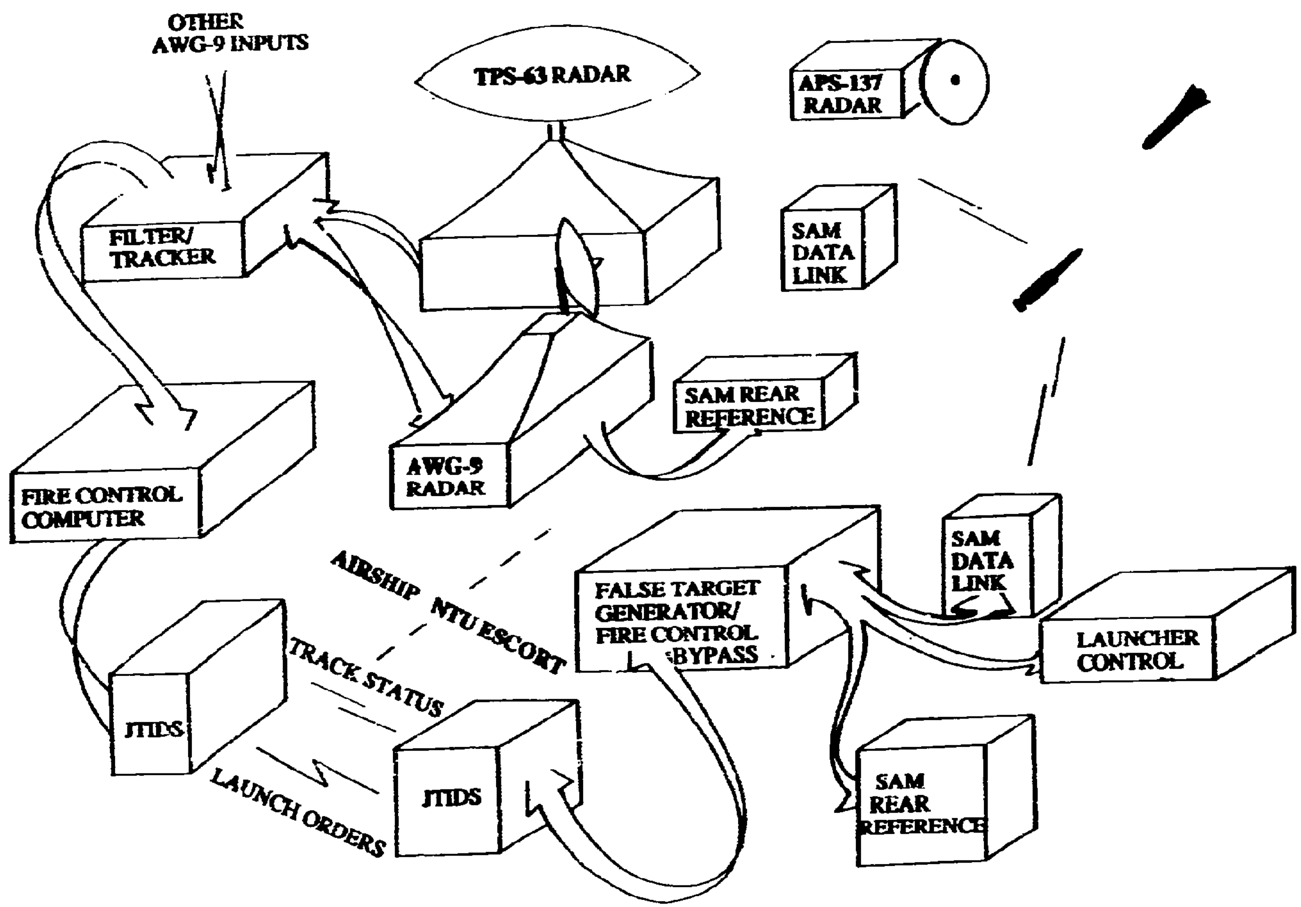

Figure 1. Airship Based Fire Control System

available to assist, the TPS-63 data will, in time, establish a track on the new target [Ref. 14]. The terminal engagement phase for the airship fire control system is assumed to last 30 seconds. The AWG-9 assigned to the engagement spends 10 seconds in a target update TWS mode and the remaining 20 seconds in target illumination. When the number of targets engaged at any one time reaches the limit of 12, and assuming the SAM launching platforms have been able to support a rate of fire requiring back-to-back terminal engagements for the number of illuminators in the system, then each AWG-9 unit in the system will be in a TWS mode for, at most, 20 seconds out of each minute. During the 20 seconds each AWG-9 unit is in the TWS mode it will be providing update data to the Tracker on all of the targets in its field of view, not just the target it is specifically assigned. This comes from the necessity of the AWG-9 to distinguish the intended target from all others in the field of view. As established earlier, tracks (Kalman filter), assuming no high rate maneuvering on the part of the target, improve over time. If the target does maneuver, the filter's estimated position for the target will deviate from the true position and the quality of the track decreases until the either the filter is supplied with enough new data to return to a high quality track status or the target breaks out of the bounds established for the filter and the track is declared "lost". When a track is declared lost, the system must start the track building process over again. To reduce the number of lost tracks, the predetermined bounds on the filter's estimates are set by the accuracy and rate of the expected data input, and must not be to tight. This requirement, not to be too sensitive based on the quality of the search radar input, sets a limit on how accurate the filter's estimate can ever be. The minimum of 20 seconds of target update data received each minute from each AWG-9 unit will improve the filter's estimate of the position of those targets in the units field of view, beyond that achievable based on search radar input alone. The newly tightened estimate will start to decay to the level supported by search radar input as soon as the AWG-9 input is removed, but the overall result will tend toward either a reduction in the length of time required for the terminal

engagement phase or a reduction in the energy level required for the SAM to have available, to complete an intercept. The impact of this additional update data will increase with the number of fire control units in the system.

2. Target Engagement

When the Tracker informs the NTU fire control computer of the track of the new target, the computer will, in the fully automatic mode of operation, review the status of the target as to friend or foe (IFF input), the engageability of the target (the SAM limits and fire control limits), and the status of engagements currently in progress (the number of tracks under fire, the number of SAMs airborne, weapons status from the surface escorts and the planned terminal phase scheduling). If a conflict exists, the NTU computer will place the track in a queue to await resolution. After this status review, if no conflicts exist, the NTU computer calculates the intercept requirements and orders the launch of a SAM, via the JTIDS data link, from the surface escort. The surface escort, which has been receiving updates on the target via the dedicated link, will fire the SAM [Ref. 11:sec. 2.5]. NTU SAM guidance is accomplished from the controlling agent by relaying, by means of the SAM data link, the target's course, speed and relative position (to the SAM). A NTU compatible SAM uses an inertial guidance unit to maintain an estimate of its own position [Ref. 15]. Upon receiving a mid-course update on the target position, the SAM calculates its own steering orders to effect intercept. The SAM also passes its derived position estimate over the SAM data link to the controlling agent. The airship will continue to pass position updates on the engaged track to the surface ship, as during the early portion of SAM flight, the ship will be responsible for maintaining the data link to the SAM. At some point in the SAM's fly out, the airship will take control of the missile's guidance. The point at which the airship takes over control from the surface escort may occur over a wide range. The earliest point that the airship may take control is when the SAM is outbound with respect to both the airship and the firing ship. The latest point for the airship to establish control is just prior to the SAM's

decent below the firing ship's horizon.[5] The airship has been monitoring the SAM data link from launch. When the airship determines the time has arrived to take direct control of the SAM, it orders the surface escort to cease transmitting to the SAM and starts transmitting on the appropriate fire control channel. From the point at which the airship takes control of the SAM data link, the interception is completed in the normal manner for semi-active missiles, with the exception explained below. [Ref. 16]

Except in the case of rapid scanning phased array radars, search radars do not generally have a position update or data rate fast enough to allow use of the search radar alone during the SAM's entire flight. At some point, a high data rate fire control radar must be made available to zero out tracking errors built up over the time of the missiles flight, to allow positioning of the SAM so the target will be in the SAM's seeker field of view at the initiation of terminal homing. Viability of the RTLOS/SLAT tactic requires the search radar involved to have a data rate sufficient to support a SAM in flight. For mechanically rotated search radars, as on NTU AAW escorts and the airship system proposed here, the data rate is the antenna rotation rate. If the search radar position update on a target is to low, uncertainty as to the targets actual position is not reduced sufficiently for successful SAM guidance.[Ref. 11:sec. 2.2] As discussed above in Track Management, the airship fire control system will be required to provide 30 seconds of dedicated AWG-9 time to support the terminal

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[5]The reason for the latest point for the airship to establish control of the SAM is fairly self-evident, the rational behind the earliest point is to ensure the airship has an aft aspect angle on the SAM, to ensure the data link antennas on the SAM and the airship are in alignment. This earliest point for the airship to take control is reached at the instant of launch, if the firing ship is between the airship and target, but the SAM must fly out past the airship before airship control is established if the airship is between the firing ship and the target.

engagement of any target.[6] The first phase of terminal engagement requires the dedicated AWG-9 unit to update the Tracker's current predicted position for the target at the start of terminal homing. The AWG-9 will provide the update by operating in the Track-While-Scan mode (TWS), for 10 seconds, over the region predicted to contain the target. The SAM's trajectory will be revised, during this phase, to maneuver to a position where the SAM seeker will be able to "see" the target at the start of the illumination phase. The terminal engagement is continued by entering into the illumination phase. In the 20 second long illumination phase, the dedicated AWG-9 unit provides the required X-band CW radiation for seeker guidance. The airship also supplies the rear reference signal required for SAM guidance. Figure 2 illustrates the proposed airship detection, track and engagement sequence.

3. Airship Compatible Surface-to-Air Missile Performance

When discussing airship controlled engagements, the assumption is made that the SAM employed is a variant of the Standard missile family at least as advanced as the NTU SM-2 ER Block III with a kinetic range on the order of 100 nautical miles [Ref. 17]. The missile is also assumed to have an average velocity, to near its kinetic range limit, of Mach 3. The assumed missile capabilities fall between the unclassified performance figures for the SM-2(ER) and those for the no longer employed Talos surface-to-air missile [Ref. 18]. The assumed engagement envelope would be comparable to that shown in Figure 3 for the Talos missile.

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[6]The rotation rate of the TPS-63 in its fastest mode of operation at 12 rpm, is marginally capable of supporting Launch on Search. To improve performance, the rotation speed of the TPS-63 is increased to 20 rpm and the antenna size increased to counter the ensuing decrease in receiver sensitivity (caused by shortening the signal integration time) the higher rpm entails. A weight increase of 200 lbs. has been allotted for the modification.

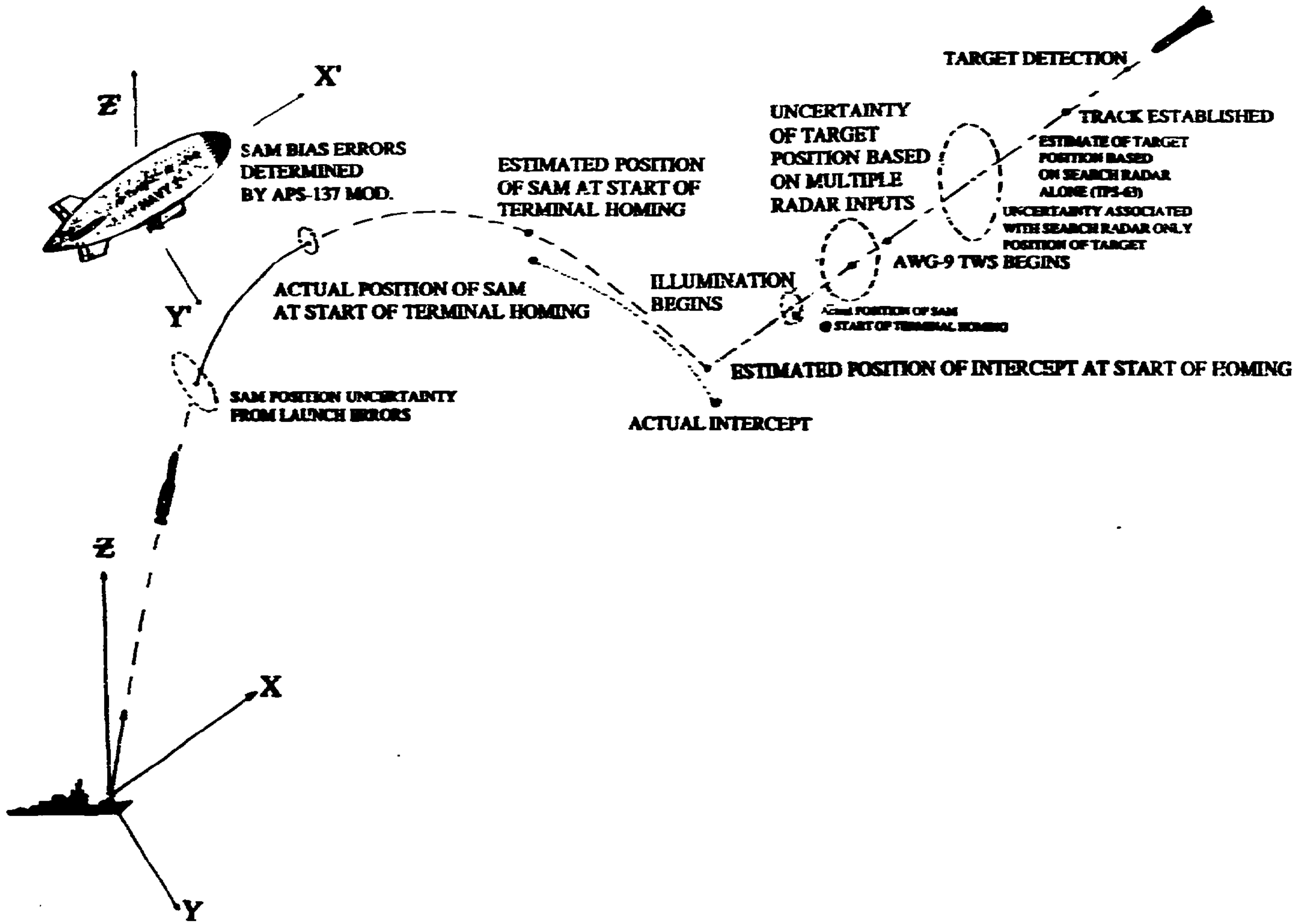


Figure 2. Sea Launched, Air Targeted Missile, Track Management

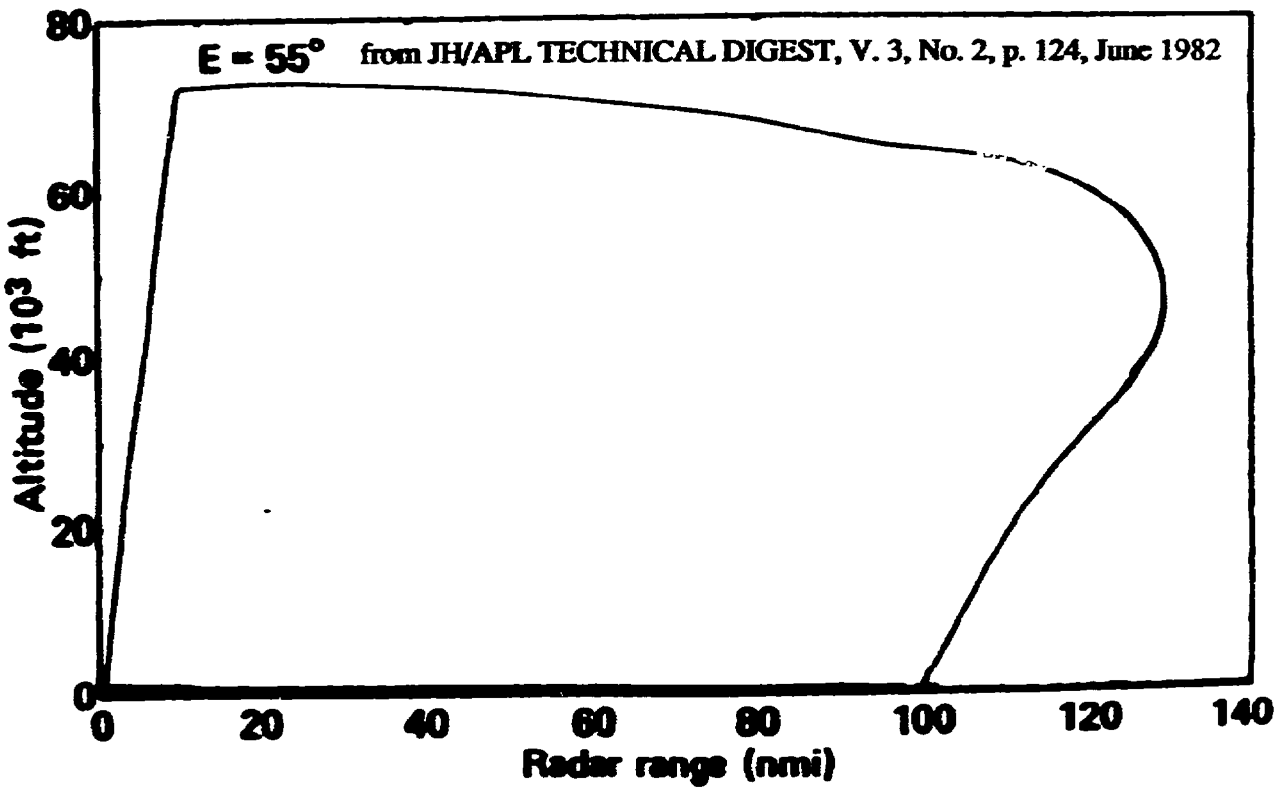


Figure 3. Surface-To-Air Missile Intercept Limits (TALOS)

4. Modifications Required To NTU AAW Escorts

Rather than modifying the existing combat system hardware and software (and estimating the cost of such modifications) the simpler expedient is taken of hard wiring a false target emulator, slaved via the data link to the airship, into the AAW weapons control portion of the escorts combat system.

5. Fire Control System Limitations

There are additional constraints on conducting fire control operations from a platform physically separated from the SAM firing units, whether the controlling unit is another surface AAW escort or an airship. One is to reduce measurement errors or uncertainty to within limits that allow an intercept. Additionally, consideration must be given the engageability of a target based on the geometry between the fire control platform, the SAM and the firing platform. The offset of the fire control platform from the SAM firing unit, relative to the target's track, is the primary factor in target engageability. The following four factors are the primary considerations for acceptable intercept geometries:

a. SAM rear reference signal antenna

b. SAM data up link antenna

c. maximum seeker slew angle

d. illuminator angle

For jam resistance considerations, the SAM rear reference and up-link antennas, are limited in field of view to, at most, the rear hemisphere of the missile. To perform an interception with a NTU semi-active homing missile, the SAM seeker antenna must be able to point directly at the target at the start of terminal illumination and stay on the target until intercept. The NTU SAM's fly out course is direct to the estimated point of interception, i.e., the SAM does not chase the target. SAM seeker maximum slew angle limits engageability when the intercept fly out course would require the seeker to try to look behind the maximum

allowable angle. Such a geometry would occur when making an attempt on a target with a speed advantage over the SAM, with the intercept to take place after the target is past and opening. Before the SAM seeker can locate the target an external source must illuminate the target. Problems occur when insufficient radiation from the external illuminator is reflected from the target toward the SAM. The target can be expected to re-radiate the impinging illuminator energy omnidirectionally in a hemisphere whose base is a plane perpendicular to the angle of illumination incidence. If the SAM seeker line of sight to the target lies outside of the hemispherical reflected illuminator energy, an intercept cannot occur. This situation will occur over a portion of the track of any target whose track passes between the airship and the firing unit.

If the offset between the airship and firing escort is less than 25 nautical miles, it can be shown most of the intercept geometry problems occur in only a small portion of any overall target track. This remains true over a broad range of the primary interception limiting factors. The adverse impact of intercept geometry is eliminated when the airship operates inside of the surface horizon of the firing unit, about 15 nm. When the airship is inside of the firing unit's surface horizon, engageability problems still exist, but when a target cannot be engaged from the airship, it will be engageable by the surface AAW escort. When the airship is inside of the firing unit's surface horizon, the airship is considered *essentially co-located* with the firing unit.

For a human operator to *"eyeball"* where engageability of a target begins and ends, would be a difficult task, i.e., to determine target engageabilty based on simple radar scope displays alone. When the airship is linked to multiple surface escorts, the ability of an operator to judge the limits of engageability from radar data alone is most unlikely, considering the engageability patchwork each airship and surface ship combination would generate.

The resulting problem is termed *targeting ambiguity*. While targeting ambiguity is a serious problem for a human operator, it represents only a small additional work load for current computer driven fire control systems.

To reduce the impact of fire control measurement errors and interception geometry limitations, the following equipment modifications and restrictions will apply to airship fire control system:

a. for any engagement, the airship may be linked to only two NTU configured AAW escorts

b. the maximum offset examined from the airship to linked escort is on the order of 15 nm

c. SAMs are tracked from launch to 25 nm in order to measure bias errors in the SM-2 inertial guidance unit[7]

d. the airship is capable of making a precise measurement of the range and bearing to the launching escort at the instant of SAM launch

e. the lower limit of the variable PRF of the AWG-9 radar is lowered to increase the unambiguous range resolution [taking advantage of the low clutter (low speed) airship environment]

f. AWG-9 antennas are increased from a 32 to a 72 inch diameter, improving system performance by a factor of two

B. CONCEPT OF OPERATIONS

The airship will deploy with the surface battle group or convoy as outlined in the original concept for the surveillance airship (Appendix B, p. 132). The scenarios presented, with minor exceptions, will evaluate the performance of a single airship. However, particularly in the battle group scenario, multiple airship operations may be desirable. The specification

[7]An upper envelop mounted APS-137 radar is modified to act as 3-D precision tracker by splitting the feed to an additional antenna. The additional antenna is rotated in the vertical plane, instead of the normal horizontal, to act as a height finder.

for 96 hours on station is primarily driven by the worst case assumption of single airship operations. If two to three airships are actually used, the requirement for 96 hours between refueling evolutions becomes of secondary importance. When multiple airship use is planned, reducing the fuel load to 48 hours on station will make available approximately 10,000 lbs. for additional mission payload, such as externally slung sensors, expendable counter-measures, point defense (Sparrow) or UAVs. While operating at the reduced fuel load, three airships would support the mission payload of four fully fueled airships.

The airship's maintenance will be the responsibility of the 25 man airship crew. The maintainability of the airship will support deployments of at least six months, with 30 day line periods followed by ten days for maintenance. A force structure of 21 airships will support the continuous deployment of three airships to the Pacific (Seventh Fleet) and three airships to the Atlantic (Sixth Fleet). Airship deployments will be on a 18 month cycle, i.e., one year between deployments.

Airships will participate in the pre-deployment exercises of the surface group or squadron with which they are to deploy. The airship commanding officers will report directly to the commander of the surface group or squadron.

C. AIRSHIP CONFIGURATION

The sources for the basic airship system parameters used here are, primarily, the work of the Naval Air Development Center, Warminster Pa. (NADC) and associated contractors in airship design requirements, and the previously cited work of WAI on the ongoing development of a 2.3 mcf displacement, airship. This airship is currently in the final design stage under the auspices of the Defense Advanced Research Project Agency.[Ref. 19]

The impact of the fire control system on the airship design is principally centered on the overall weight of the system. The following estimates are made for the mission payload

required for three variations of the airship fire control system. The fire control system variations are:

a. 2 AWG-9 systems

b. 6 AWG-9 systems

c. 12 AWG-9 systems

1. Mission Payload Weight Estimates

The weight of the base line mission payload, as shown in Table 1, is first estimated. The base line mission payload is that which is carried on all airship variants. The weight of the fire control system is then estimated for each variant and combined with the base line weight for the total mission payload in Table 2.[8]

2. Airship Size

Based on the variation in the fire control system weight, the proposed airship must support a mission payload from between 23,000 and 35,000 lbs. The graph in Figure 4 is based on the NADC *Naval Airship Program for Sizing and Performance* (NAPSP), a computer based tool for estimating airship design parameters [Ref.20]. For a given airship mission payload, altitude, speed and endurance requirements, NAPSP will determine the displacement required to accomplish the mission. The curves in Figure 4 have been generated for an airship capable of cruising at 45 knots for 96 hours at a given altitude, with a maximum speed of 90 knots at the same altitude. When Figure 4 is entered at the mission payload weights calculated for the three airship variations at the 10,000 altitude, displacements and approximately 2.5 mcf, 3.0 mcf and 3.5 mcf respectively.

[8]The combat system avionics package from the ODM airship is approximately 4500 pounds. However, to allow for system growth and to provide a margin for error, 10,200 pounds is used here.

TABLE 1

WEIGHT ESTIMATE FOR THE BASE LINE MISSION PAYLOAD

Item:	Item Weight	Group Weight:
Avionics Group:		
S3-B suite		
APS-137 radar		
TPS-63 radar	10,200	
TPS-63 antenna mod	200 lbs.	
Base line Avionics sub total:		10,400 lbs.
NTU Group:		
Computers/Interface (2)	200 lbs.	
Transceivers/Antennas(2)	300 lbs.	
JTIDS	200 lbs.	
Rear Reference (2)	250 lbs.	
APS-137 SAM Track	630 lbs.	
Base line NTU sub total:		1,580 lbs.
Crew/Spares Group:		
25 men @ 220 lbs	5,500 lbs.	
Tools and Spares	1,370 lbs.	
Food, 3 lbs/day/man.	2,250 lbs.	
Crew sub total:		9,120 lbs.
Base line Mission Payload:		**21,000 lbs.**

TABLE 2

ESTIMATE OF AIRSHIP TOTAL MISSION PAYLOAD FOR 2, 6 AND 12 ILLUMINATORS
(Base line Payload + Fire Control System Weight)

Airship Variant One, 2 Illuminators:		
Fire Control Group:		
Base line Payload:		21,000 lbs.
AWG-9 (2)		2,000 lbs.
Fire Control sub total:	2,000 lbs.	
Mission Payload:		**23,000 lbs.**
Airship Variant Two, 6 Illuminators:		
Base line Payload:		21,000 lbs.
Fire Control Group:		
AWG-9 (6)		6,000 lbs.
+200kw Prime Power.		400 lbs.
Structure/Cabling.		1,000 lbs.
Fire Control sub total:	7,400 lbs.	
Mission Payload:		**28,400 lbs.**
Airship Variant Three, 12 Illuminators:		
Base line Payload:		21,000 lbs.
Fire Control Group:		
AWG-9 (12)		10,800 lbs. *
+400kw Prime Power		800 lbs.
Structure/Cabling		2,000 lbs.
Fire Control sub total:	13,600 lbs.	
Mission Payload:		**34,600 lbs.**

* Note: after 6 AWG-9s are installed, additional units are paired to reduce weight

Displacement Required to Support Given Non-Rigid Airship Performance at Altitude and Mission Payload Selected

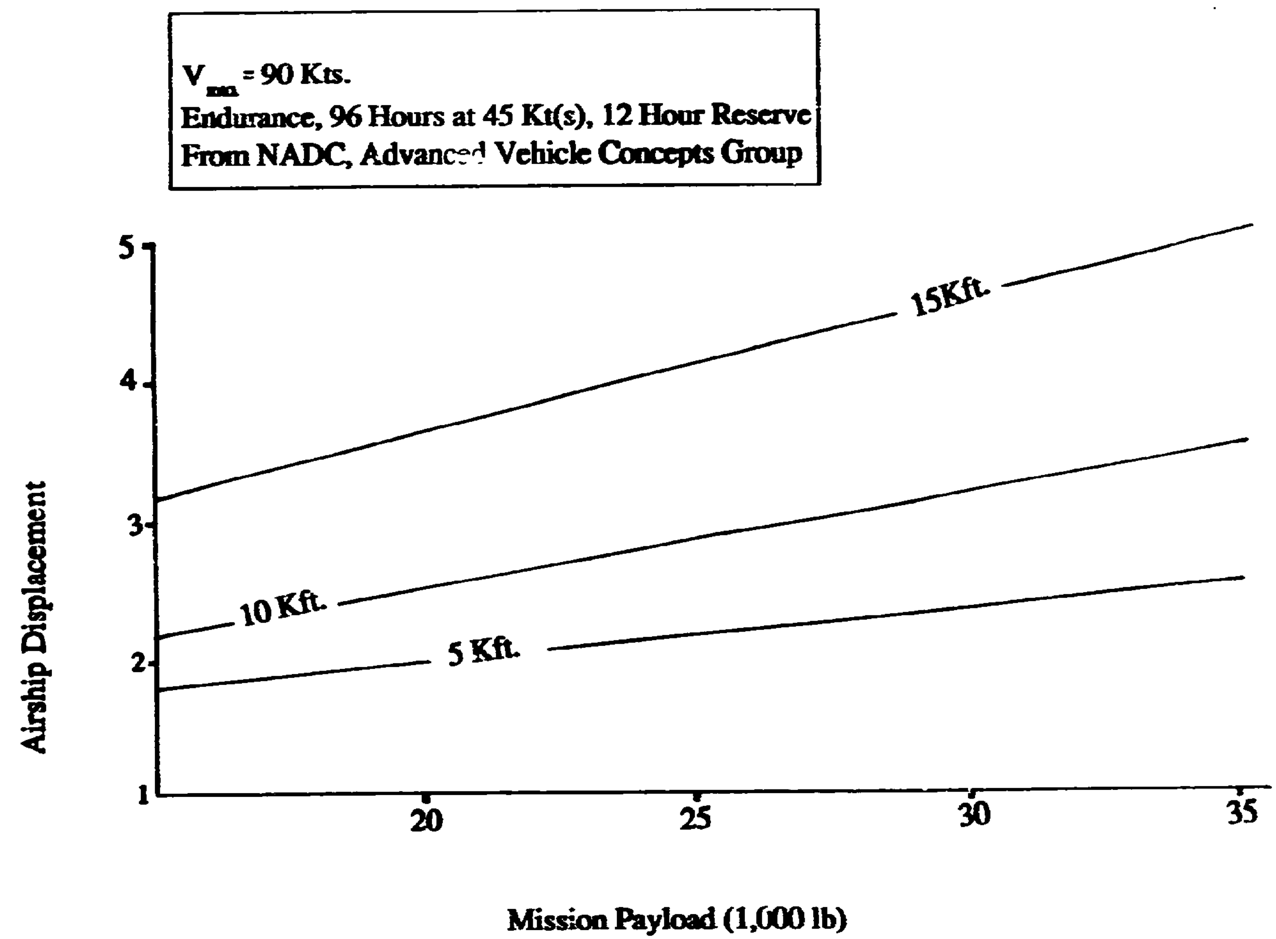


Figure 4. Mission Payload Impact on Airship Size

III. CONVOY OPERATIONS

Strategy and tactics may have changed a great deal since the end of WWII, but one constant has been the reliance on seaborne transport to maintain the logistics pipeline. Clearly the success of any maritime strategy depends on the ability to keep the sea lines of communication open. There is some debate as to whether convoys, in the traditional sense, will play an important role in future conflicts. Relying on recent operational experience in the Persian Gulf, it would appear that in the near term, alternate technologies will not replace convoys in the conventional sense.

A. THE MODERN CONVOY

If the importance of sea based transport has not changed, the nature of the merchant vessels has. The size of the vessels has increased by several orders of magnitude. The speeds which modern merchant vessels can sustain are probably twice that of their World War II counterparts [Ref. 21:p. 105]. On the other hand, the maneuverability of the modern merchant, in terms of turning radius, acceleration and stopping distance is poorer on average than the earlier more handy vessels. In view of the changes in merchant ship characteristics, convoy procedures are modified from those in WWII. The first change is the number of ships in the convoy. Rather than have 60 or more ships in a convoy, it is reasonable to suppose at most 25 ships will be included. (Based on the relative number of ships available and the question of how much can be afforded to be lost, a la Atlantic Conveyor.)

The second change is the spacing between ships. In the Second World War spacing for ships in convoy was roughly a rectangular grid of 1000 X 800 yards with 800 yards the distance between ships in any column and 1000 yards, the distance between columns [Ref.

21:p. 103]. Considering the size of current vessels, the convoy grid in the scenario will be 2000 X 2000 yards.

1. Convoy Scenario

Under the assumption that the air and naval forces have checked the enemy major surface combatants, the open ocean threat to convoys would be submarines and long range bombers. The exact number and type of escorts would be determined by the relative significance of the threat. That is to say, if the threat was primarily from torpedo firing submarines it would be desirable (for a given level of resources) to have the minimum resources in AAW platforms with the bulk in ASW platforms. As the relative threat level shifts toward ASCM firing aircraft and submarines the most desirable mix of escorts shifts to favor the AAW platforms. It is this situation that extends the useful life of older AAW escorts through "flexible transition". This scenario will explicitly examine the ASW aspects of convoy defense only to the extent to which AAW defensive requirements impact ASW.

2. Threat Assumptions

The threat launch platforms against the convoy are considered to be:

a solitary bomber

b. a "cell" consisting of one spotter aircraft with 2 raider aircraft

c. diesel and nuclear powered submarines

In all cases, the accompanying missile threat will be low flying ASCMs over the speed range of .75 to 1.5 Mach. In the case of aircraft, each will carry either 2 long range (150 nm) missiles or 4 medium range (60 nm) missiles. The submarines will be limited to launching missiles within 60 nm of the convoy center.

Further assumptions shall be:

a. raiding aircraft are not constrained by fuel

b. raiding aircraft and submarines will have real time or near real time targeting data available via second party

c. ASCMs are designed to cross the target's radar horizon between 25 and 50 feet.

The tactics of the raiders are considered to be essentially free, in that they may choose to:

a. attack convoy units indiscriminately with regard to merchant vessel escorts

b. give a high priority to targeting merchant vessels

c. target the primary AAW units early to set up convoy for future air attack

d. target the ASW screen to set up for submarine attack

Stripping the escorts is particularly attractive in a Pacific basin scenario, with long transits involved and thus the longer period over which to exploit a success over the escorts. Targeting the escorts would seem to be less attractive in the relatively short runs through the North Alantic in support of NATO. This selective targeting will considered to be the extent of aircraft/submarine cooperation.

As per current policy, the AAW screening platforms will be selected from the older classes of Cruiser/DDGs which have received service life extending upgrades. The convoy scenario, shown in Figure 5, will be examined with various combinations of AAW platforms, with and without first generation airship augmentation.

B. MEASURING THE EFFECTIVENESS OF THE AAW SCREEN

The ASCM threat level posed in the scenario is, at most, 8 missiles. This threat is relatively low, compared to a battle group scenario. The most direct measure of AAW screen effectiveness is the number of firing opportunities the screen can generate against a penetrating aircraft or missile. Commonly called "firepower" or "depth of fire" (DOF),

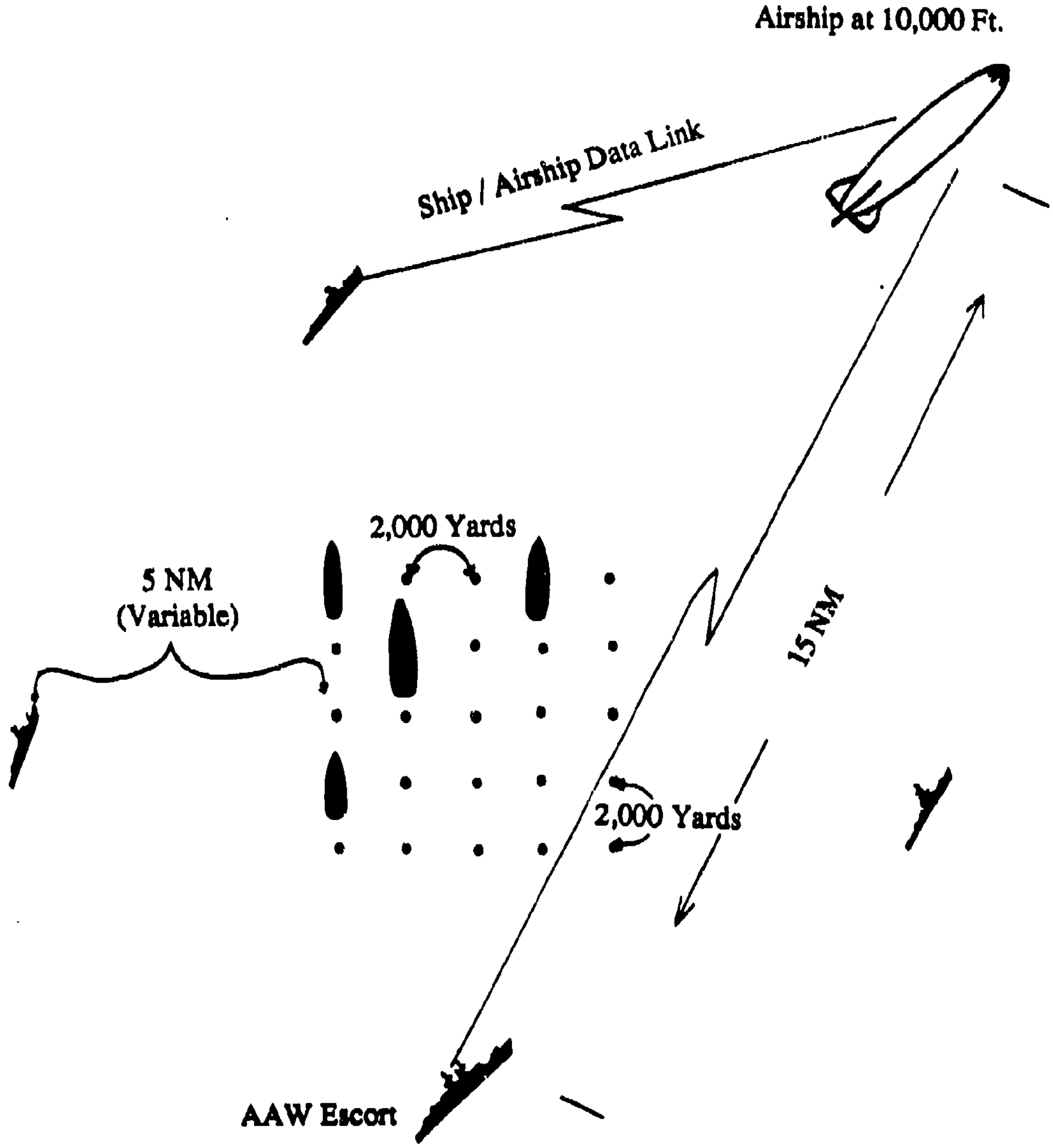
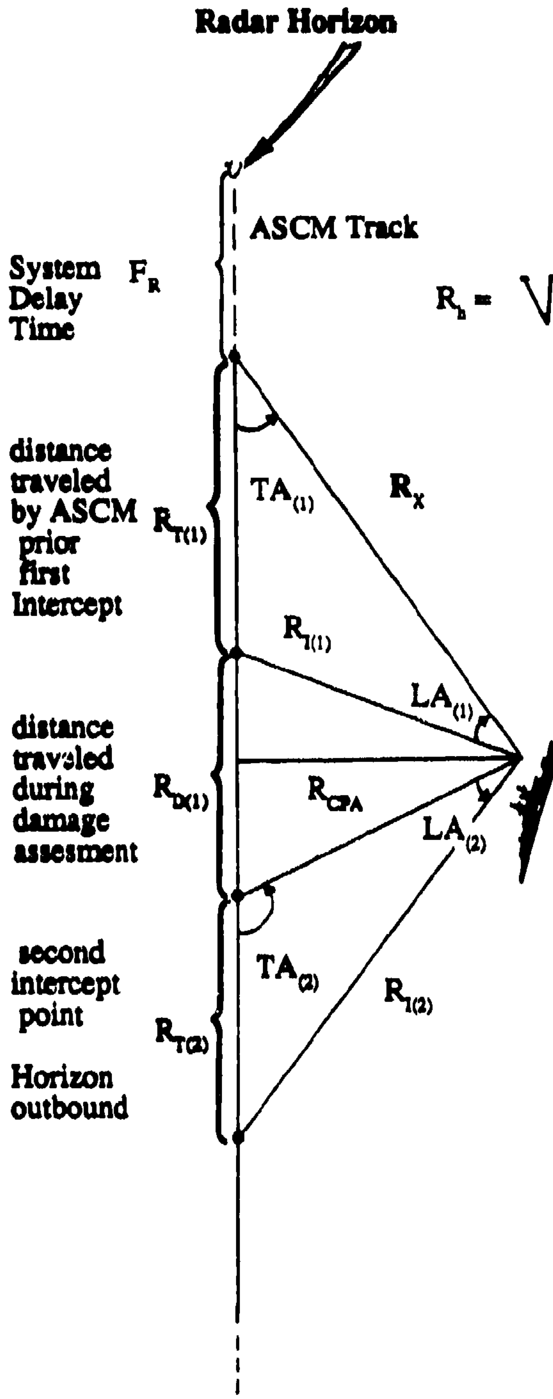


Figure 5. Typical Convoy with Airship and Surface Escorts

this measure, as here used, is modified from that described in *Naval Operations Analysis* (*NOA*) [Ref. 22:pp. 228-239]. Also considered as measures of effectiveness will be elements derived from the DOF figures, the maximum cross range for a given depth of fire, the maximum cross range at a targets closest point of approach and the area of coverage. The modifications to the *NOA* definition of depth of fire are to allow for the impact of low flying missiles and the limitations of fire control system.

The first change concerns the use, in *NOA*, of the surface to air missile's maximum effective range as setting the range of the first intercept. In the case of the low flyer, unless the SAM of interest has an extremely short maximum effective range, the radar horizon combined with the fire control system reaction time and the SAM's average velocity will determine the actual point of earliest intercept. For the convoy scenario, with the ASCM crossing the radar horizon at 25 feet, and assuming a search radar height of 75 feet, the radar horizon is calculated to be at 17 nm. Figure 6 shows the assumptions for the radar horizon and the DOF calculations.

A delay has been added to the time a missile crosses the horizon until a surface to air missile is launched, to account for the time interval for detection, establishing a track/fire control solution, assigning and firing the SAM. The time delays for the older technology AAW escort are 25, 30 and 35seconds. The delay encountered while utilizing the first generation airship will be 120 seconds from the airships radar horizon for air launched over-the-horizon shots and the escorts reaction time for "pop-up" sub launched missiles. The actual detection range is random variable dependent on many environmental and detection system parameters. Those readers uncomfortable with the horizon simplification may feel free to consider the system delay times for the surface ships to represent three values of a detection time random variable chosen to represent good, fair and poor detection conditions.



Radar Horizon:
The value is calculated as:

$$R_h = \sqrt{2\,\text{Radar Ht.(ft.)} + 2\,\text{ASCM Ht.(ft.)}}\ \frac{5280}{6000}$$

in nautical miles

F_R: Firing Range, represents Fire Control System delay from ASCM crossing Horizon until SAM is launched.

R_X : In NOA [Ref. 22:p. 230] this is the Maximum Effective Range of SAM. Here it is the range from ship to ASCM at the instant of firing first SAM.

R_T and R_D : R_T is the distance traveled by the ASCM from SAM launch to Intercept, R_D is the additional distance the ASCM travels during the damage assesment period

TA is the angle from the ASCM flight path, to the line of sight of the ship to the ASCM (i.e., Target Angle)

LA is the angle from, the line of sight of the ship to the ASCM, to, the intercept point. (Lead Angle)

R_I is the distance the SAM travels from launch to intercept.
Note: Last intercept attempt must occur prior to ASCM recrossing the horizon outbound.

(see Appendix B, p. 129 for DOF Equations)

Figure 6. Depth of Fire Calculations for Low Flying Targets

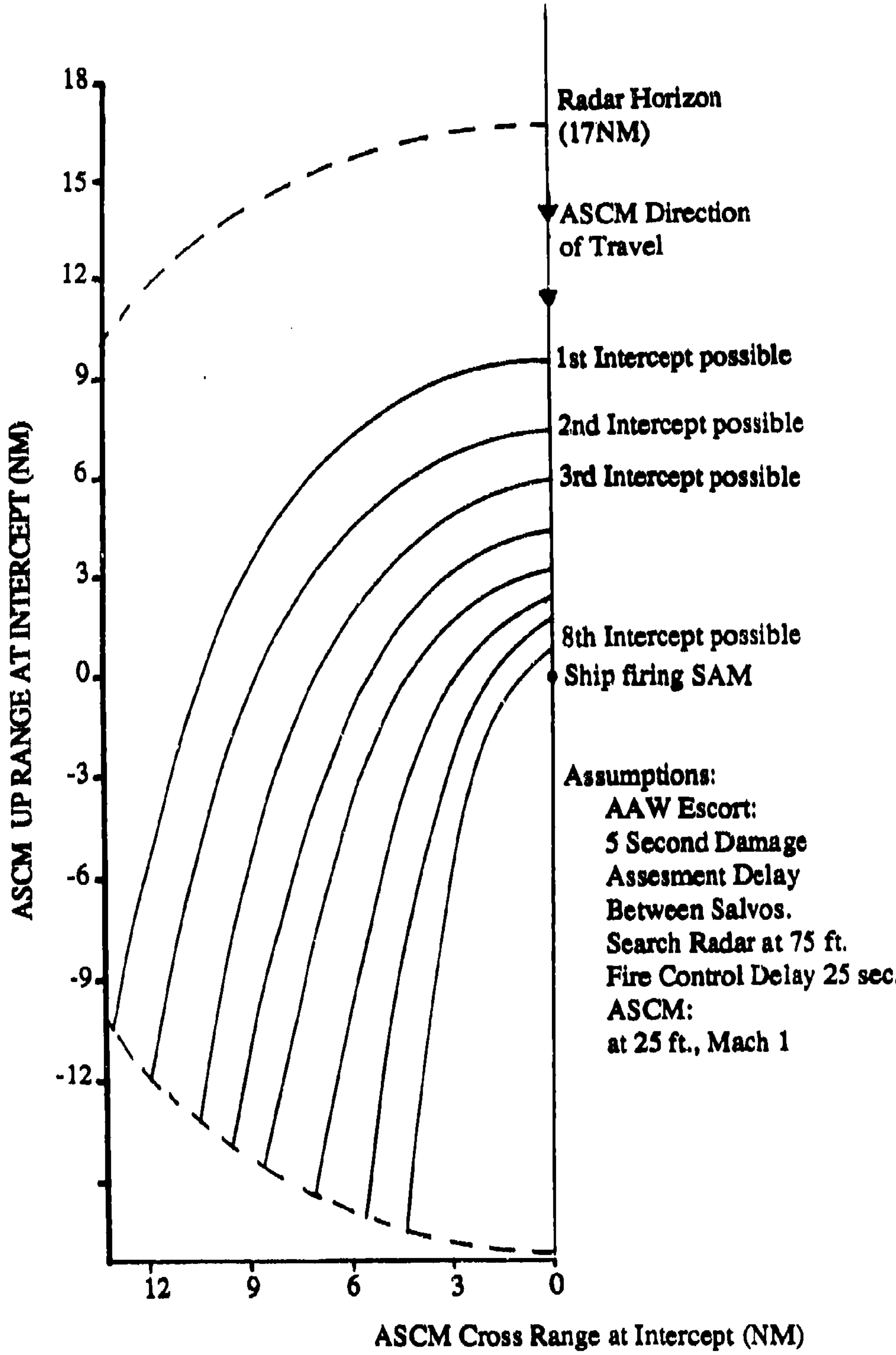
The second modification allows for a brief period after an apparent interception to assess damage to the target. Five seconds will be used for the damage assessment delay between interception and launch of the next SAM. The third departure from the *NOA* method involves taking into consideration the SAM system minimum engagement range. The SAM systems in this scenario will be considered to have minimum ranges between 3 and 6 nautical miles. The minimum range for airship assisted interceptions will be 15 nautical miles from the SAM launching ship when co-located, to up to the maximum allowable airship/AAW ship offset of 25 nm. These limits are imposed on airship assisted interceptions to reflect data link and position errors limits of the first generation airship. For pop-up targets the minimum range will be at least the minimum range of the SAM launching ship and 2 nm from the airship.

1. Depth Of Fire For Convoys Without Airships

Utilizing the concepts developed in Figure 6, depth of fire calculations were performed for target velocities from Mach .75 to Mach 1.5 in increments of 0.25.

A contour is plotted in Figure 7, for a AAW escort utilizing a Mach 3 SAM with only the assumptions for target velocity and height, fire control and damage assessment delays, included. In using the depth of fire plot, the contour axis of symmetry is turned to parallel the targets path (from top to bottom) through the engagement zone. The plot has no relationship to the firing ship's true heading, it represents the engagements possible for a ASCM crossing 10 nm astern of the ship at a right angle as well as a cruise missile approaching the ship bow on. Each of the curves, counted from top to bottom, represents the locus of all succesive interception points on targets who's flight path is parallel to the axis of symmetry.

In Figure 8 the contour is shown plotted with the further assumption for the AAW ships fire control systems minimum range constraints. Note, in Figure 8, the seriously disruptive effect minimum range constraints have on the depth of fire achievable on closing targets which have paths that pass inside the minimum range. The most immediate



Fir re 7. DOF Contour, Mach1 ASCM, 25 Second Delay

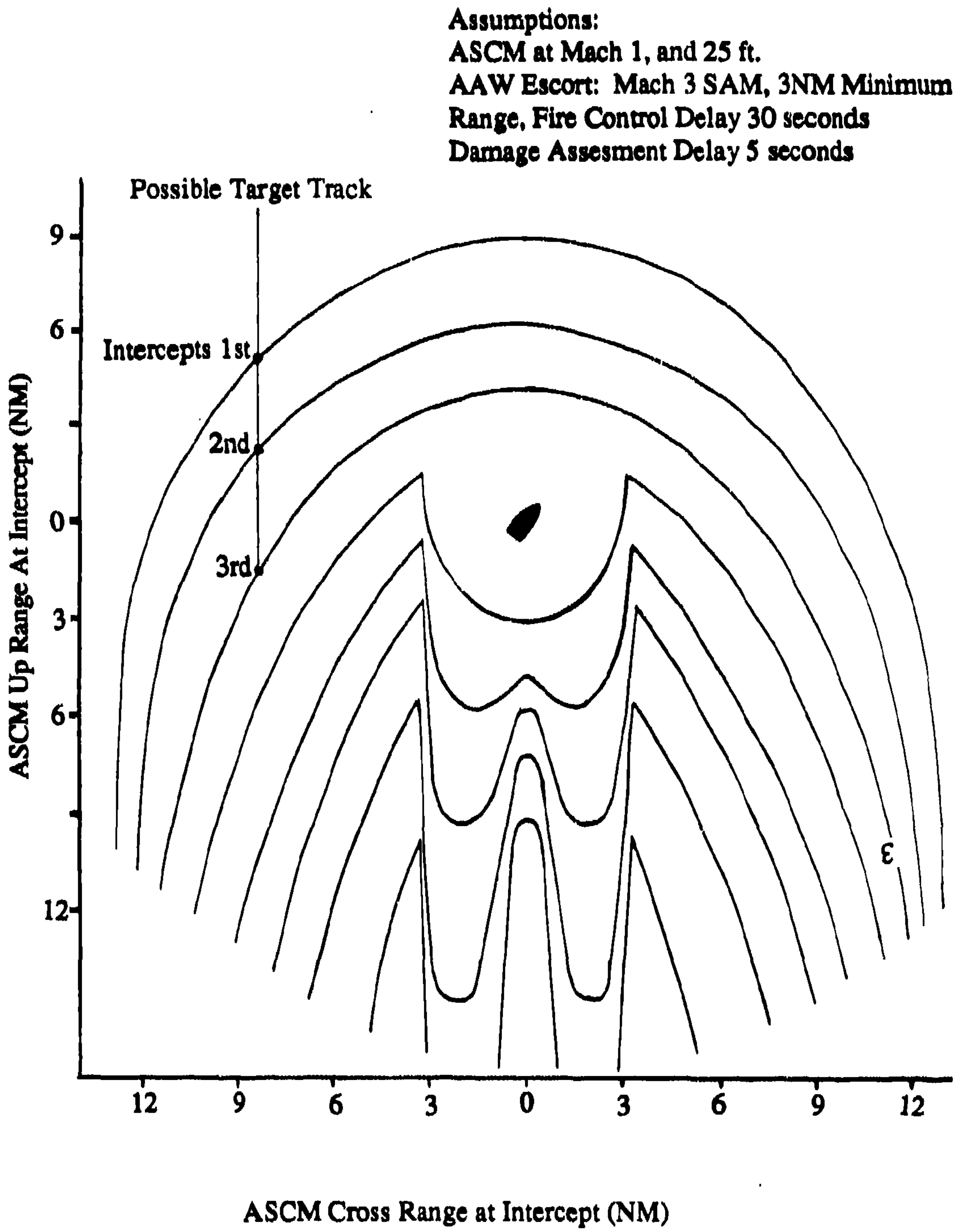


Figure 8. DOF Contour, SAM Minimum Range 3 NM

impression is, in trying to counter an AAW platform with such a depth of fire contour, the path of least resistance is to attack the AAW ship.

In Figure 9 the cross range at intercept verses successive interception opportunities, on closing targets, is plotted for various ASCM velocities and AAW ship reaction times. The curves are plotted as continuous functions even though depth of fire is strictly a discrete phenomena to simplify the presentation. Depth of fire is seen to drop off rapidly with both an increase in system reaction time and ASCM velocity. The minimum range at which a fire control system may successfully complete an intercept appears to be a critical factor for any interception opportunities beyond 2, across a wide range of system parameters and ASCM speeds.

2. Depth Of Fire, Convoys With First Generation Airship

Considering now, a convoy accompanied with an airship, contours developed for a NTU AAW ship acting as a launch platform for a first generation airship performing intercept control. Figure 10 shows the resulting contour against a raiding aircraft flying at 25 ft. above the water at 0.75 Mach when the SAM launching ship and airship are essentially co-located (within 15 nautical miles). In this case, airship augmentation takes place for those interceptions prior to the AAW ships radar horizon, at which point the AAW ships unaugmented DOF contour would be added. The AAW ships unaugmented DOF contour is not shown in Figure 10 for reasons of scale.

In Figure 11 the range at intercept verses successive interception opportunities when augmented by airship, on closing targets, is plotted for the range of potential ASCM velocities and the AAW ship reaction times. The data from unaugmented escorts is included for comparison.

3. Minimum Significant Depth of Fire

The large number of ships in the convoy presents a special problem in the defense against low flyers. The convoy, even with expanded spacing, represents a rather dense group

DOF on Target Crossing Escort's Field of Fire with a
Closest Point of Aproach (C.P.A.) as indicated.
3 sets of 3 curves are shown. Each set of curves is for the indicated Target velocity. The individual curves in a set represent performance with fire control delays of 35, 30 and 25 seconds from inner to outer curves respectively.
Additional Assumptions:
Search Radar Height = 75 feet
Target Height above water = 50 feet
SAM Average Velocity = Mach 3.0
Damage Assesment Delay between SAM salvos = 5 seconds

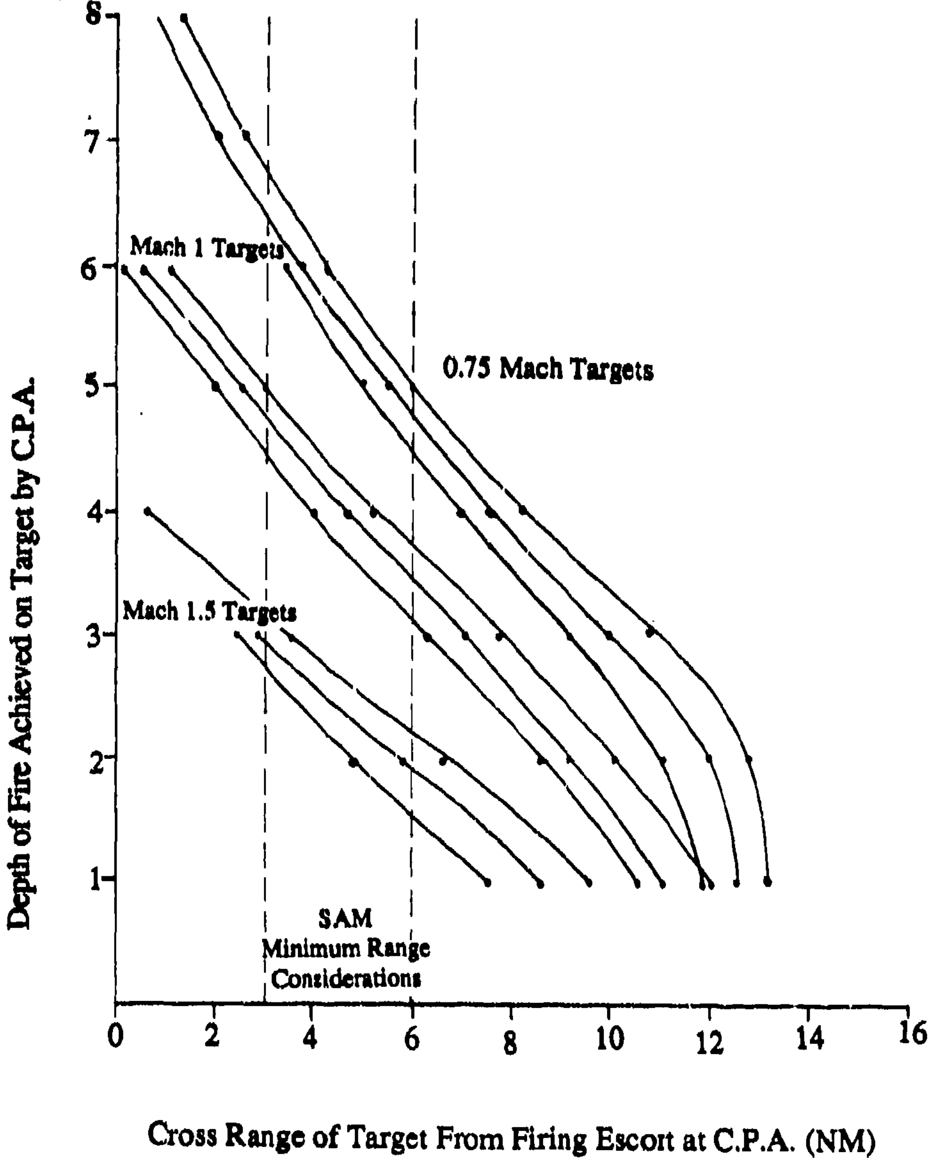


Figure 9. DOF of Surface Escorts on Crossing Targets, by C. P. A.

Assumptions:

Long Range Bomber @ 0.75 Mach, 25 ft.

Airship @ 10,000 ft. within 15 nm of Escort

Fire Control Delay ≈ 120 seconds

Escort using Mach 3 SAM

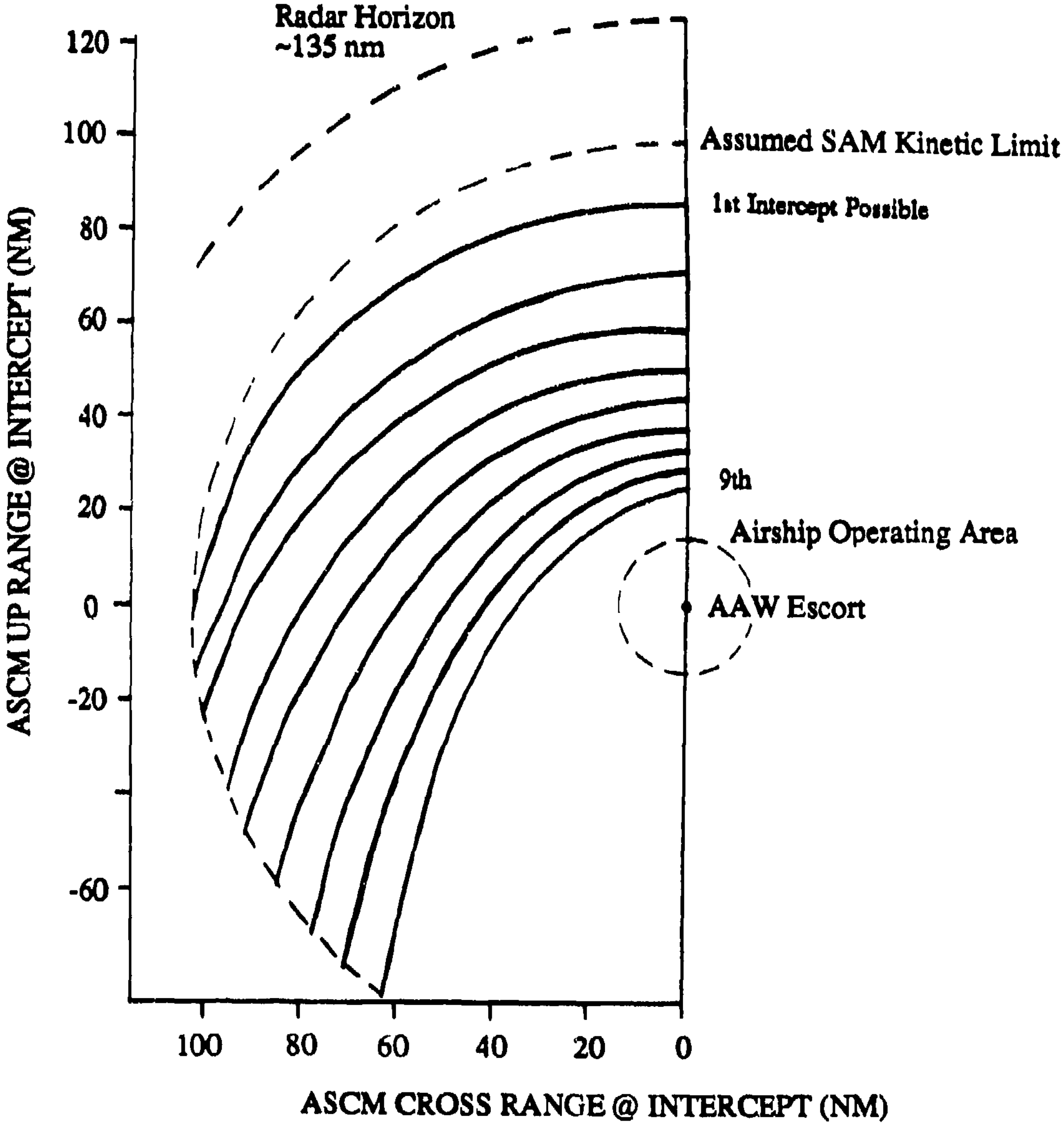


Figure 10. DOF Contour, NTU AAW Escort with Airship Targeting

DOF on Targets Crossing Airship/NTU ESCORT Field of Fire
with C.P.A. as indicated
Assumptions:
AIRSHIP at 10,000 feet and essentially co-located with NTU ESCORT
SAM Average Velocity = Mach 3.0
Fire Control Delay ≈ 120 seconds
Damage Assesment Dealy = 5 seconds
Target Height = 50 feet
Target Velocity as indicated

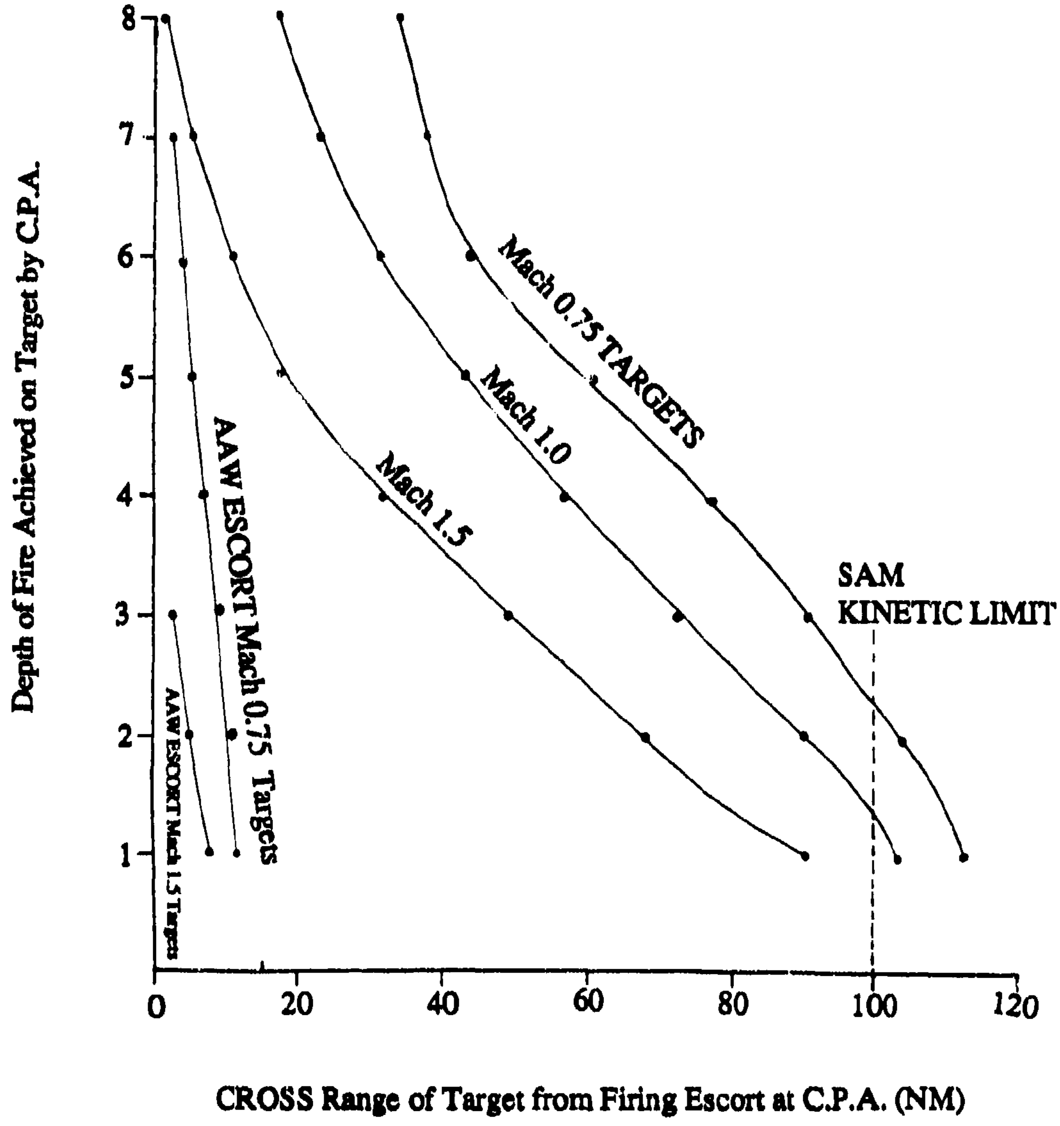


Figure 11. DOF, Airship Targeting on Crossing Targets

of large objects which will screen a portion of the horizon from the escorts. The term "flicker" arises from the successive masking and unmasking of the ASCM as it crosses the random gaps created by the convoy in the AAW ships radar coverage. Fire control systems need to see a target for a period of time in which to establish a "track" and generate a fire control solution. Flicker will increase the time required to generate the track. Once a "track" is established and a missile is fired, when the target passes behind the superstructure of a convoy unit, the track and thus the intercept opportunity is likely to be lost. Loss of the intercept opportunity is almost guaranteed if line of sight to the target is interrupted during the terminal homing phase of SAM flight. Raiding aircraft can be expected to utilize flicker to their advantage, by using the convoy ships as a screen to interfere with the detection and interception of low flying ASCMs. As will be seen, fire control from the airborne system will avoid the flicker effect.

A closed form optimal solution for AAW ship spacing does not exist for the case of low flying anti-ship missiles. For this paper a simple graphical method for determining the best spacing for a given number of AAW escorts was developed by using transparent overlays of the DOF contours shown earlier.

Raiding aircraft will be looking for broad avenues of attack (of several miles width) which have a readily discernible lower average depth of fire. It is assumed that gaps in coverage of less than 1 to 2 miles would not be detected by raiding aircraft working in close to the convoy (utilizing the radar horizon) because the raider is developing a targeting picture by taking numerous "short looks". And by similar considerations, raiders using a stand off long range surface search aircraft will not be able to take advantage of small gaps because of range and bearing resolution limitations of the search aircraft radar. Table 3 lists the smallest significant depth of fire for a given number of AAW escorts.

TABLE 3

MINIMUM SIGNIFICANT DOF AGAINST ATTACK BY MACH 1 ASCMS

(ASCMs Launched at Over-The-Horizon Ranges)

Number of Escorts	Minimum. Significant DOF *
1	0
2	2
3	5
4	7

* Intercepts completed by 1 nm from convoy, ASCMs at 25 feet, system reaction time 30 seconds, SAM average velocity, Mach 3, SAM minimum range 3 nm.

At the very least, if there is any aircraft threat to the convoy, at least 2 AAW ships must be detailed. It is understood ships which are primarily considered AAW escorts may have an excellent ASW capability. However, the requirements of performing as a close in AAW escort (5-15 nm) will probably seriously compromise the use of the escort's passive ASW ability, which requires 35 nm of distance from the convoy.

Table 4 re-examines the above scenario for the smallest significant DOF or AAW escorts augmented with first generation airships. Additional assumptions are the airship and escorts are essentially co-located and the escorts are within 5 nm of the convoy outer limits.

It is apparent the first generation airship could have a significant impact on AAW effectiveness in a convoy scenario. The addition of the first airship generates a minimum significant DOF with only one AAW escort which equals that from 4 unagumented escorts. Of perhaps greater significance, a single AAW escort augmented with an airship will have

TABLE 4

MINIMUM SIGNIFICANT DOF AGAINST ATTACK BY MACH 1 ASCMS

(Airship Augmented Convoy)

Number of:

Escorts	Airships	Min. Significant DOF
1	1	7
2	1	16
3	1	18
4	1	19
3	2	25
4	2	33

Intercepts completed by 1 nm from convoy, ASCMs at 25 feet, system reaction time 30 seconds, SAM average velocity, Mach 3, SAM minimum range 3 nm.

on the order of 2 to 4 firing opportunities (referring back to Figure 10) on launching platforms seeking to close the convoy to within 60 nm, to use shorter ranged ASCMs. The ability of the first generation airship/NTU team to force raider standoff ranges to increase, and or conduct intercepts on raiding aircraft, presents the following benefits to the convoy:

a. both the number carried and terminal velocity of the available low flying ASCMs decreases at greater launch ranges

b. as the range at release of the ASCM increases, the targeting accuracy falls off (of particular interest when escorts are targeted)

c. a significant DOF may be maintained for the defense of ASW escorts at ranges on the order of 40 nm from the AAW escorts where before 10 nm was the limit

d. the time between interception attempts is substantially greater indicating raids of a higher density could be handled

The net result is, convoys with airship augmented AAW escorts are likely to "see" smaller air raids than convoys with unaugmented escorts. The smaller raid of lower density

leads to the conclusion that less capable escorts in terms of number of launchers and reloading times may be utilized.

4. **Depth of Fire Measures in the ASCM Firing Submarine Environment**

The cruise missile firing submarine is most often considered in the context of a threat to aircraft carriers, or perhaps to the carrier's underway replenishment group as opposed to a threat to merchant convoys [Ref. 23]. The ability to "pop-up" without appreciable warning anywhere from a few miles from the target vessel to more than 60 miles away (targeting problems aside) gives the submarine a great deal of flexibility in "surprising" the victim's defenses. The missile launching submarine strikes directly at the airship's primary contribution to the convoy's protection, the ability to shoot early and often, and for this reason it must be considered a threat to convoy ships.

First, convoy defense is considered for unaugmented AAW escorts. The most immediate consequence of submarine launched ASCMs is the existence of a "dead zone" around the periphery of the convoy, for which AAW defense is essentially zero (the exception is the chance the missile will pass inside the range of an escorts close-in weapons system, including the potential for the target being the escort). This zone exists because of the AAW escorts lag time from target appearance to SAM launch. Under the assumption of firing delays in the convoy scenario of on the order of 25 to 35 seconds, Table 5 shows the horizontal distance from the outer edge of the convoy to a distance inside of which a submarine launched attack will give surface AAW escorts no opportunity to intercept.

For missiles launched at ranges greater than those in Table 5, escorts should have at least one opportunity for engagement after the ASCM passes and is opening from the escort. Likewise, the submarine launch distance from the escort which will allow the first interception opportunity on a closing ASCM will be on the order of 8-10 nm for the .75 Mach missile, 9-11 nm for Mach 1 missile, and 12-15 nm for a missile closing the convoy at Mach 1.5, based on the system reaction time assumed.

TABLE 5

CONVOY AAW ESCORT NO SHOT ZONE AS A FUNCTION OF DELAY TIME AND ASCM SPEED

(ASCM Launch Range (nm), From Escort)

	ASCM Speed		
Delay Time.	.75 Mach	Mach 1	Mach 1.5
25 sec.	3.12	4.17	6.25
30 sec.	3.75	5.0	7.5
35 sec.	4.38	5.83	8.75

Intercepts completed by 1 nm from convoy, ASCMs at 25 feet, SAM average velocity, Mach 3, no SAM minimum range considerations.

SAM system minimum range considerations, which where ignored in Table 5, are included in examining escort DOF contours. Figures 12 and 13 display Depth of Fire contours for Mach 1 ASCMs launched at ranges of 10 and 13 nm from the AAW escort, given a 25 second system reaction time and a 3 nm minimum range. Relative to DOF contours for over-the-horizon launched ASCMs (those launched at 17 nm or greater for surface escorts alone), the depth of fire is compressed and narrowed. Minimum firing range, while a significant factor in the OTH case, becomes crucial against pop-up missiles.

The minimum significant depth of fire for a given number of AAW escorts was calculated based on the assumptions that the escorts (with a 30 sec. reaction time) were 5 nm from the convoy and a Mach 1 ASCM was launched 10 nm out from the escorts. The depth of fire is then recalculated with a launch at 5 nm out from the escort. The results are shown in Table 6.

In the case for a convoy defended by 4 AAW escorts, at the 10 nm ASCM launch, one escort will be completely blocked by the convoy. Two of the escorts will have to wait for the missile to clear the horizon, to the effect they suffer another 15 second delay in firing, thus

Assumptions:
Submarine Launched,
Mach 1 ASCM (@ 25 ft.) launched 10 nm from SAM firing Escort
AAW Escort using Mach 3 SAM, with 3 nm minimum range, 25 second Fire Control Delay, 5 second Damage Assesment Delay

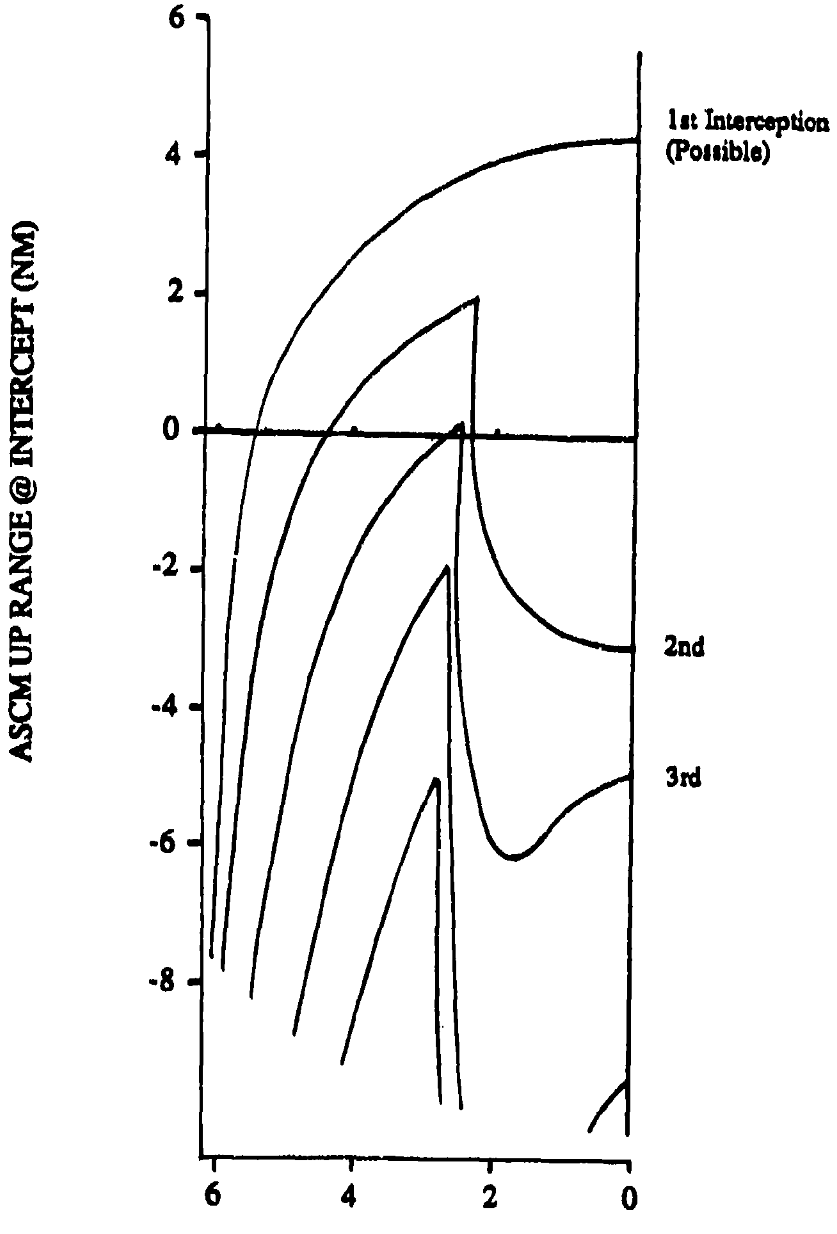


Figure 12. DOF Contour, Submarine Launched ASCM (10 nm)

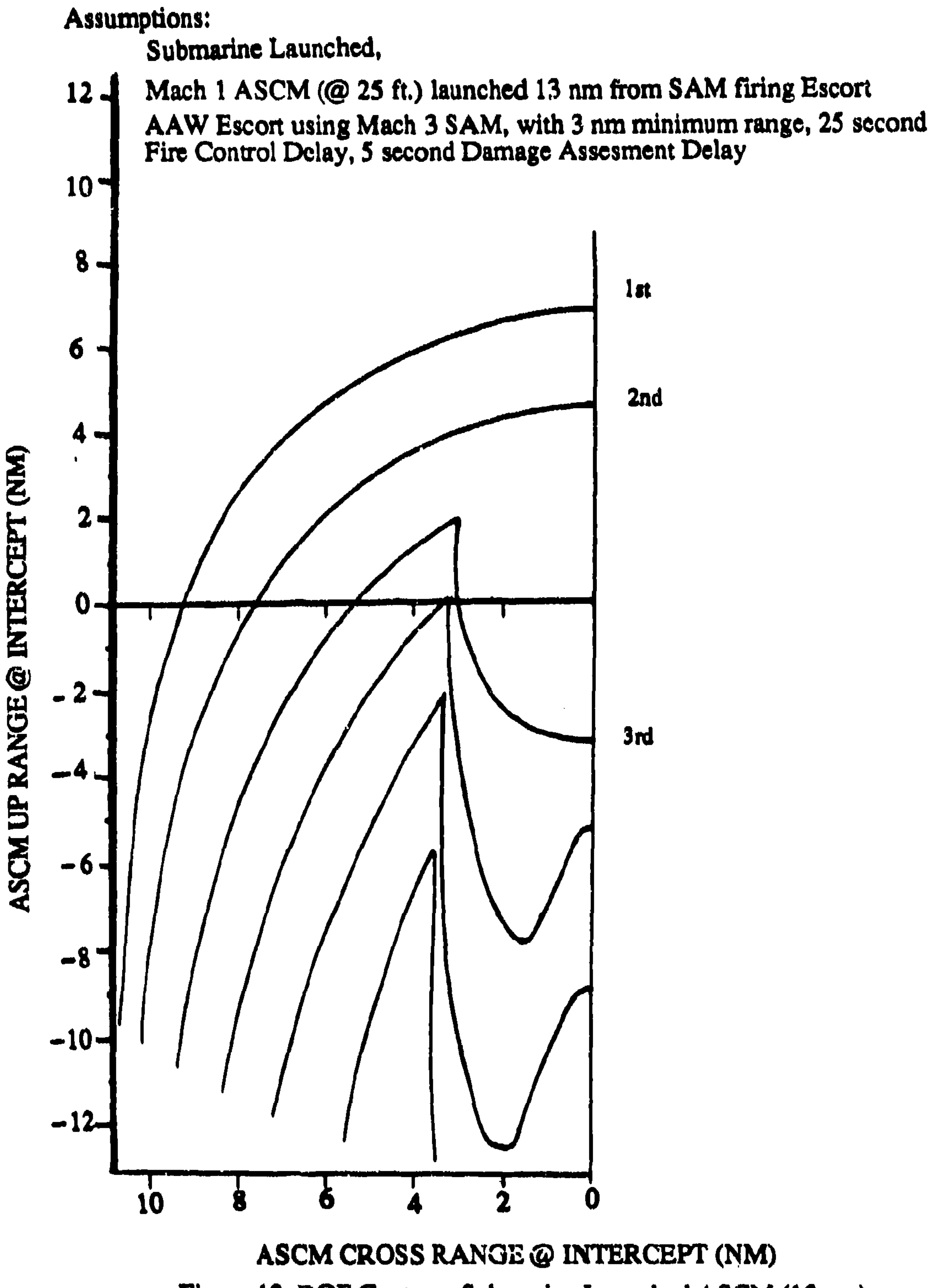


Figure 13. DOF Contour, Submarine Launched ASCM (13 nm)

reducing the intercept opportunity to one apiece. Only the escort to which the ASCM makes its closest point of approach will have 2 firing opportunities. When the firing range is reduced to 5 nm, in the 4 escort case, 2 escorts will be blocked by the convoy and the other 2 escorts will only have one intercept opportunity each before they too are blocked by the convoy body.

TABLE 6

MINIMUM SIGNIFICANT DOF AGAINST ATTACK BY MACH 1 ASCMS
(ASCMs Submarine Launched)

Launch @ 10 nm from Escorts (17.5 nm from convoy center)	
Number of Escorts	Minimum Significant DOF
1	0
2	2
3	2
4	4
Launch @ 5 nm from Escorts (12.5 nm from convoy center)	
Number of Escorts	Minimum Significant DOF
1	0
2	1
3	2
4	2

Intercepts completed by 1 nm from convoy, ASCMs at 25 feet, SAM average velocity, Mach 3, SAM minimum range, 3 nm.

a. ***Airship Supported Convoys***

The submarine launched attack scenario was re-examined with the NTU AAW escorts augmented with first generation airships, with the results shown in Table 7.

TABLE 7

MINIMUM SIGNIFICANT DOF AGAINST ATTACK BY MACH 1 ASCMS
CONVOY ESCORTS AUGMENTED BY AIRSHIPS
(ASCMs Submarine Launched)

Launch @ 10 nm from Escorts (17.5 nm from convoy center)

Number of:		
Airships	Escorts	Minimum Significant DOF
1	1	2
1	2	4
2	3	6
2	4	8

Launch @ 5 nm from Escorts (12.5 nm from convoy center)

Number of:		
Airships	Escorts	Minimum Significant DOF
1	1	1
1	2	2
2	3	3
2	4	4

Intercepts completed by 1 nm from convoy, ASCMs at 25 feet, SAM average velocity, Mach 3, SAM minimum range, 3 nm.

The improvement in minimum significant DOF of the airship augmented AAW escorts, in the 10 nm launch case, is based on a reduction in both the delay to fire time and blocking of fire by the convoy body. In the 5 nm launching case, the increased DOF is attributed to the increased firing zone.

The scenario, with or without airships, is extremely sensitive to the assumption of a 3 to 1 speed advantage of the AAW escorts SAM over the submarines ASCM. The use of actual missile average velocities (of the sort generally used in handbooks) is of little value, in that the major portion of the region of engagement tends to be inside the acceleration zones of the missiles concerned. The decline in performance, as the 3 to 1 SAM speed advantage is lost, does not appear to favor either airship augmented or unaugmented escorts, as both fare poorly. Over a very narrow region, at the point at which escorts lose the ability to engage ASCMs by reason of reaction time, a slight advantage goes to a greater number of unaugmented escorts over a smaller number of augmented escorts. The advantage exists by reason of a greater relative density of close in weapons systems in the former case. The favor is slight considering the limited (by design) ability of such systems to engage targets crossing at ranges of greater than 1 to 2 nautical miles. The airship augmented intercepts also suffer from targeting ambiguity which arises when a ASCM would pass between the firing escort (in lateral range) and the controlling airship. This problem can be reduced by having an airship take station very close to convoy center and establish a link with 2 opposed escorts. This tactic reduces targeting ambiguity because the airship induced intercepts, in this case, are derived from bringing in shots from the disengaged side of the convoy. Thus the airship and the offside escort utilized always see a closing target.

As the submarine launching distance increases beyond 17 nm from the escorts, the definite advantage of airship augmentation is reasserted. When ASCMs are launched from 30 nm, as shown in Table 8, airship augmented AAW escorts have recovered approximately half of the DOF from the case where ASCMs are launched outside of 100 nm.

TABLE 8

MINIMUM SIGNIFICANT DOF AGAINST ATTACK BY MACH 1 ASCMS, CONVOY ESCORTS AUGMENTED BY AIRSHIPS (ASCMs, Submarine Launched from 30 nm)

Number of: Escorts	Airships	Minimum Significant DOF
1	1	3
2	1	8
3	1	10
4	1	11
3	2	12
4	2	15

Intercepts completed by 1 nm from convoy, ASCMs at 25 feet, SAM average velocity, Mach 3, SAM minimum range, 3 nm.

The submarine launched ASCM poses a definite hazard to convoy operations. There is a substantial zone from in which a submarine may launch a missile, which for all practical purposes, is not countered by older AAW escorts. The most critical factors in reducing this "dead zone" rest with decreasing system reaction time, ensuring a large speed advantage for the SAM over the ASCM, reducing the SAM minimum range and maintaining the widest possible field of fire. The airship, in the dead zone, only helps in achieving the latter.

Before the entire convoy escort disposition is distorted to cover a close in submarine launched missile attack, the utility of a missile shot from the submarine's tactical point of view should be considered. When the submarine has successfully penetrated to inside of 5 nm a missile attack would have to be seen as an attempt to reduce the probability of an immediate counter-attack from the surface escorts, while launching a conventional torpedo attack. The submarine that has succeeded in closing to 5 nm undetected acoustically is a serious threat from torpedoes alone, regardless of any ASCM threat it might pose.

The most serious impact of the close in, submarine launched, missile attack on convoys protected by airships would be the requirement to hold the AAW escorts inside of 10 nm from the convoys limits and keep the airship(s) tightly centered on the convoy. With no serious threat of submarine launched missiles inside of 20 nm, the convoy commander would be able to have a significant DOF against raiding aircraft while being free to move the AAW escorts as far as 30 nm away from the convoy and/or open the convoy spacing to 10 nm between units. The latter offers the potential, in ASW terms, of operating as a moving "protected lane". When submarine launched cruise missiles are introduced to the AAW picture, augmenting AAW escorts with airships still allows for a 2 to 1 reduction in the number of escorts required for a given level of defense, while at the same time, increasing the flexibility of escort and convoy stationing with respect to ASW concerns.

IV. THE SURFACE ACTION GROUP

The threat environment in which the Surface Action Group is expected to operate is that which induced the requirement for a flexible transition to "retire" older less capable AAW escorts to convoy duty. Generally, for convoys, the threat, in terms of numbers and density, was considered to be low. Conversely, the much increased potential threat to the SAG underlies the requirement to construct billion dollar "state of the art" AAW cruisers and destroyers [Ref. 23:p. 120]. In particular, the threat posed by anti-ship cruise missiles, while currently serious, is rapidly escalating toward un-manageability from both the proliferation of the nations possessing ASCMs and the increasing capabilities of the missiles produced. It is not unreasonable to expect the capabilities of anti-ship missiles to continue grow with respect to higher cruise and terminal velocities, lower detectability (reductions of radar cross section and lower altitude flight) and the built-in capability to defeat active and passive counter-measures (smart weapons). The Surface Action Group must be prepared to operate in a high density "saturation" environment where an adversary could be expected to attempt to overwhelm AAW defenses by attacking with a large number of closely spaced weapons. Depth of Fire alone, as used as a measure of effectiveness in the convoy scenario, is not sufficient to describe weapon system effectiveness in situations where an attempt at saturation of the defense is a reasonable expectation. Thus, another analytical tool must be applied in the Surface Action Group scenario.

A. AAW EFFECTIVENESS THE SAG ENVIRONMENT

In the final analysis, the purpose of the airship is to allow the surface fleet survive to accomplish its mission. The cost of providing a given level of survivability would be the most direct measure of effectiveness, but is difficult to define analytically.

With the introduction of Aegis technology to the fleet the Johns Hopkins Applied Physics Laboratory published a means for evaluating the effectiveness of carrier battle group AAW defenses [Ref. 24]. The APL model utilizes defense in depth. AAW defenses are broken down into the following categories:

a. "Outer defense zone" where coverage is provided by the aircraft carrier E2-C/fighter aircraft.

b. "Inner defense zone" where the vicinity of the ships is covered by "area defense" AAW cruisers and destroyers.

c. "Self defense zone" where short ranged "last chance" weapons are employed.

The concept is to measure the effectiveness of the carrier airwing in terms of the number of AAW defense ships required to destroy leakers (successful penetrators) from the outer to inner zones.

The substitution of the airship and alternatives for the carrier airwing was a logical and appropriate step, the viability of the surface battle group without carrier or land based aircraft is among the central issues of the "Revolution at Sea".

In formulating the APL model, the following information or assumptions about the total AAW system are stated or implied:

a. The size of the enemy raid is given or an upper bound estimated.

b. The duration of the raid is given or bounds estimated.

c. The system overall probability of kill is represented by the probability of a single missile destroying its intended target (single SAM P_k).

d. The number of times a ship can engage a target (depth of fire) is known or calculated from the system parameters, and shall be at least 2. Vertical launch escorts may meet the depth of fire requirement, of 2 engagement opportunities per target, by firing single salvos of multiple SAMs.

e. The area covered by an individual AAW ship is wide enough and the physical disposition of the ships is such as to allow the assumption of symmetric loading of the defenses. (Implicit Assumption)

Based on the previous, the maximum number of ASCM's that the entire AAW inner defense force can successfully defend against is approximated as:

A =SAS X SP , [EQ. 1]

where;

A = the number of ASCM's which can be destroyed by the battle group AAW ships

SP = the number of AAW area defense ships

SAS = the number of ASCMs a single AAW ship can successfully engage from a given type raid

and;

SAS = (ER X T) / EE , [EQ. 2]

where;

ER = the Engagement Rate of an individual ship

T = the Time available for engaging targets, for low flyers, essentially the raid duration

EE = the average number of times a target is expected to be engaged (based on the single SAM P_k)

When the above parameters are established, the number of AAW area defense ships required to successfully defend against a given raid of specific duration may be plotted as is shown in Figure 14. Here the assumption is made that each AAW ship may engage 10 targets per minute with a depth of fire of at least 2. The model indicates a purely linear or additive relationship exists between defensive ships with regard to the ability to counter the threat. The implicit assumption of symmetric loading of the defenses is critical to the foregoing assumption of linearity. The model requires the external estimation of the airwing's effectiveness in "pre-filtering" the raid. For example, given a Combat Air Patrol effective-

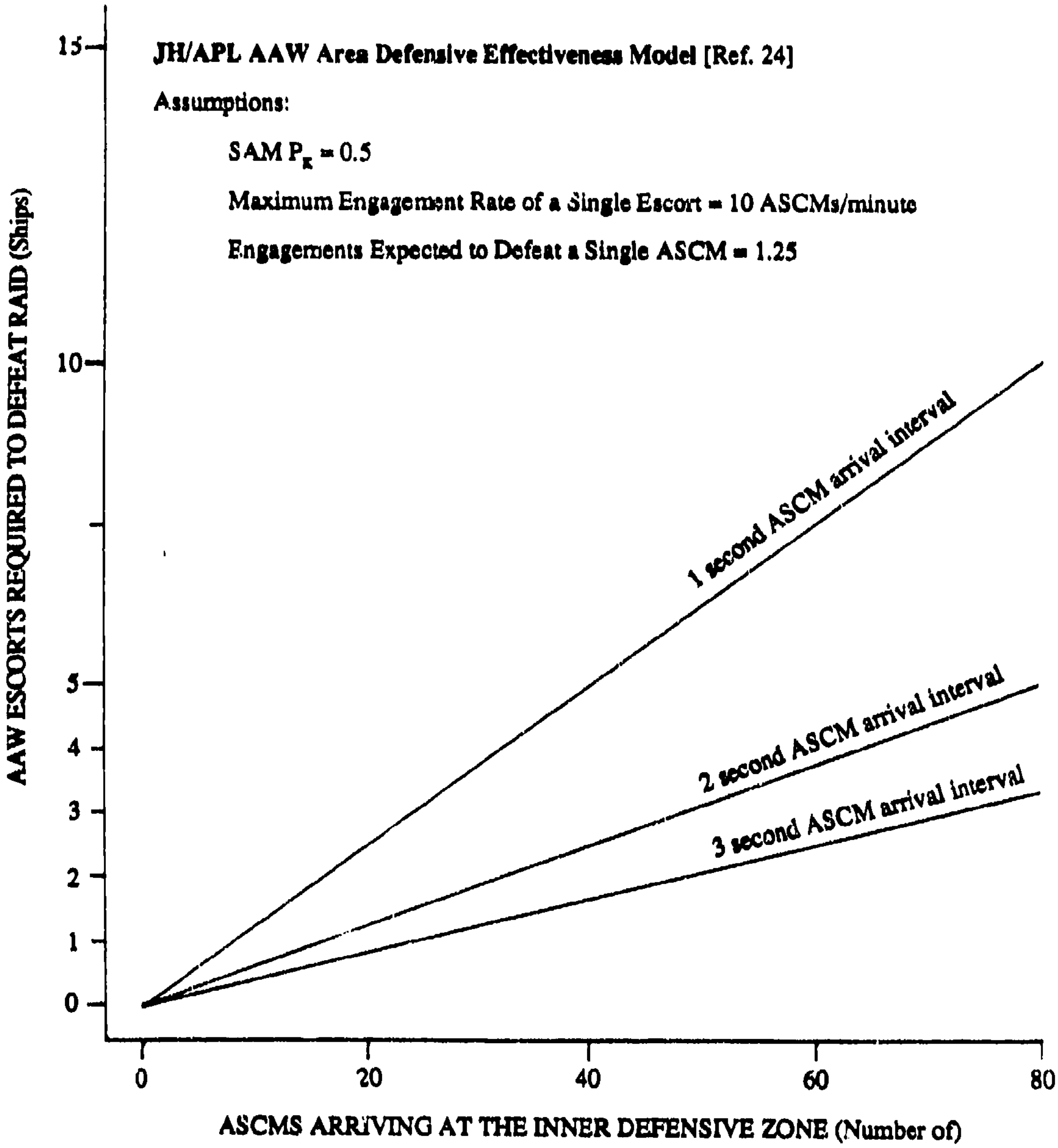


Figure 14. AAW Escort Requirements Based on Raid Size and Arrival Interval

ness of 50% against a 60 ASCM raid, the AAW escorts would be faced with a 30 missile raid. For the level of AAW capability shown in Figure 14 the requirement is established for at least 4 AAW escorts if the aircraft have not affected the ASCM arrival interval.

The value or effectiveness of the airwing is not only measured by how many missiles are destroyed prior to the inner defensive zone. Perhaps even more important is the ability of the fighter aircraft to influence the ASCM arrival interval. Referring once more to Figure 14, if the fighters can interfere with the attacker's command and control element to the extent the missiles arrival interval is forced from the initial assumption of 1 second to a 3 second interval, while at the same time only destroying 10 of the 60 missiles, the net effect is to reduce the inner AAW defensive requirement from 4 to 2 AAW escorts.

B. WEAPON SYSTEM ASSUMPTIONS

It is pointed out in the APL paper that when all of the primary factors involved in an AAW engagement are considered, the result will be a family of curves for each scenario, with each curve depending on the variation of one of the factors. For the purpose of this analysis, the following assumptions are made about the characteristics of the weapons systems in the scenario.

1. Initial Threat Assumptions

a. the threat seen by the AAW area defense ships will be ASCMs launched beyond the ships radar horizon except for those missiles launched from tactical aircraft. ASCMs from tactical aircraft will be launched inside of the ship's radar horizon to the attacking aircraft, but after launch the missile will drop out of sight.

b. the ASCMs are low flyers which cruise at 50 feet or less, dropping to as little as 6 feet in the terminal phase.

c. ASCM speeds will vary from Mach 1 to Mach 3. For computational purposes, missile speed will be 10 times the Mach number, in nautical miles per minute.

d. the raid size is 60 ASCMs

e. launch platforms will be surface ships and bombers at ranges greater than 150 nautical miles and tactical aircraft at from 60 to 30 nautical miles

f. the radar cross section of targets[1] (for the "L" band frequency) will considered to be at least (in square meters):

1. > 5.0 for tactical aircraft
2. > 0.75 for missiles capable of launch beyond 100 nm
3. > 0.25 for missiles capable of launch at 60 nm
4. > 0.1 for missiles capable of launch at 30 nm

2. AAW Escort Assumptions

The primary AAW escorts are area defense cruisers employing the latest "state of the art" technology, consisting of:

a. 3-D, frequency agile, phased array search radar

b. 100 vertical launch, semi-active homing Surface to Air Missiles of the Standard missile family

c. support 24 missiles in-flight

d. 4 illuminators to support terminal homing

e. a fully automatic mode of operation allowing for SAM launch against a low flying ASCM within 10 to 20 seconds of the target crossing the radar horizon.

f. Time required to determine if an intercept was successful and salvo additional SAMs of 2 seconds.

g. a minimum SAM intercept range of between 2 and 6 nautical miles

h. SAMs employed will achieve an average velocity of between Mach 2 and Mach 3 within 5 nm from launch

With the above parameters fixed, and given:

a. the ship system's single SAM probability of destroying (P_K) an engaged target is 0.95,

b. the AAW ship fires a 2 SAM salvo in each engagement (2 SAMs to meet DOF requirement of model)

c. Each target is engaged independently of any other

The overall probability of a state of the art AAW escort destroying an engageable target, during a single engagement, is 0.975.

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[1] With rcs increasing with speed/range considerations.

Secondary AAW escorts are cruisers and destroyers constructed in the 1960's but "upgraded" in the late 70's and early 80's with the following capabilities:

a. mechanically rotated and scanned air search radars

b. mechanical dual rail launchers with a 1 or 2 launcher configuration (20 to 40 seconds reload times)

c. 2 illuminators per launcher

d. threat reaction time of on the order of 30 seconds

e. minimum intercept range of 2 nautical miles

f. uses a Mach 3 variant of the Standard missile family, Extended Range, with interception capabilities of on the order of 100 nautical miles

g. a magazine capacity of at least 60 SAMs

h. when modified, may operate with an airship to conduct over the horizon AAW engagements

3. Airship System Assumptions

The characteristics and assumptions for the first generation airship, as delineated in the airship system description, are reiterated and further refined here.

The air search radar is based on the Westinghouse TPS-63. This radar operates in the "L" band and has the capability to detect low flying fighter sized targets at ranges in excess of 140 nautical miles and track small radar cross section target drones at ranges greater than 90 nautical miles at the airships 10,000 foot operating altitude.[Ref. 25] As a supplemental air search system, inputs from all of the installed Hughes AWG-9, "X" band, search/fire control radars are used.

The fire control system consists of:

a. from 2 to 12 AWG-9 systems, enhanced with 72 inch antennas

b. NTU fire control computers (2)

c. NTU missile communication systems (2)

d. JTIDS, providing a dedicated control link to and from the airship to 2 NTU configured AAW ships[2]

The following amplifying limitations apply:

a The airship can only control SAMs from NTU AAW ships with the dedicated JTIDS/Remote Launch modifications.

b. To forestall jamming of the fire control link, reduce relative position errors and reduce interception ambiguity, the airship must be within 25 nautical miles of the missile firing ship.

c. Each missile control data link from ship to airship will support at most 12 SAMs at any given time, i.e., the maximum number of missiles in flight given a link to 1 AAW ship is 12. If the airship is linked to 2 AAW ships, 24 missiles may be supported at any given time against 12 targets. As the number of AWG-9 systems is increased, the number of tracks engaged and number of missiles in flight will remain fixed at 12 and 24 respec tively.

d. Terminal Engagement time required is 30 seconds.

e. Given the near term threat is not of reduced radar cross section, the airship detection range is the horizon and detection of low flyers will occur at the radar horizon less 10%.

f. Fire control tracks/solutions will be determined by 10 nm after detection (no more than 20 additional scans on a Mach 1 target, i.e., from horizon to track is approximately 80-120 seconds.)

g. the airship may operate at altitudes of at least 10,000 feet

With the above parameters fixed, and given:

a. the airship/AAW ship system's single SAM probability of destroying an engaged target (P_k) is 0.5

b. the AAW ship fires a 2 SAM salvo in each engagement

Then assuming each target is engaged independently of any other and considering the outcome of each SAM fired as an independent event, the overall probability of destroying the target during a single engagement is 0.75.

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[2]Alternatively the airship may drop one of the two possible AAW escorts from the link to free one JTIDS channel for an airship-to-airship link . The airship-to-airship data link is to allow for establishing fire control quality tracks from passive ESM cross bearings.

It can be seen the distribution of targets destroyed by the airship/ NTU escort team is a binomial random variable with the parameters:

P, the probability of success in any trial = 0.75

Q, the probability of failure in any trial = 0.25

N, the number of trials

Thus the expected number of successful interceptions is simply the expected value of the binomial distribution:

E(intercepts) = N x P, [EQ. 3]

with the variance:

Var(intercepts) = N x P x Q, [EQ. 4]

In this case, N is limited to engagements initiated outside of the AAW ships in company's firing range and in any event, no engagements after the time of arrival of the first enemy weapon at the airship or SAM firing ship's location. The first restriction is to prevent counting engagements which are simultaneously those of the airship and another ship in the battle group. The second restriction, that of limiting the counting of engagements to the "time on top" of the first enemy weapon, is to prevent considering interceptions performed after the airship and or SAM firing ship are subject to being damaged or destroyed. These restrictions, while obviously understating the airship's capabilities, avoid the complication of making the distributional assumptions required to support a Monte Carlo simulation.

C. WEAPON SYSTEM PERFORMANCE IN THE THREAT ENVIRONMENT

The goal is to estimate the limits of the single ship in the threat environment. The saturation limit or "roll back" point is reached when the stream of inbound ASCMs has moved the point of interception so close to the defending ship that the next missile in the specified stream is inside of the ship's ability to successfully intercept, i.e., place the SAM warhead close enough to the ASCM to be within the lethal radius. This minimum range is

made up of a number of factors, often lumped together, some of which are quite variable, others of which are more rigid. Among the more rigid is the mechanical performance of the missile launch sequence. Many times the launch sequence limits alone are given as the "minimum range" of the system. Considered in the launch sequence are questions such as; What is the booster burn time? Can the missile start to turn toward the target while in boost phase? If not, how long until it can? Additionally, for the vertical launch case, consideration must be given to the time taken to pitch over from the vertical plane to direction of the ASCM. These considerations factor together to determine where and when in space the missile will be when ready to start homing. This may not be the minimum intercept point. Dealing with a semi-active homing missile, some minimum amount of SAM terminal homing must take place. The terminal homing phase may have some overlap with the launch sequence, depending on when the seeker head of the SAM is free to search, but homing cannot commence if there is no illuminator shining on the target. The value for terminal illumination the shipboard fire control algorithm is using to control the firing sequence and illuminator scheduling is critical. For a given minimum terminal homing time, the minimum range of interception will also depend on the acceleration rate of the SAM in conjunction with the velocity of the ASCM. Thus, the minimum interception range possible against an ASCM becomes greater the higher the cruise missile's velocity. The point in time and space at which the ship makes its last intercept depends on both illumination scheduling and the SAM time of flight required. For this analysis, when the engagement under consideration is being conducted by a surface escort alone, the criterion for determining if the engagement is permissible will be illumination scheduling, to vary between 8 and 10 seconds, and a minimum time of flight, from SAM launch to impact, to vary from the scheduled illuminator period to 2 seconds over the scheduled illuminator period. When an engagement is conducted utilizing the airship, the cutoff criterion will be when the engaged ASCM reaches the range of first intercept of the firing surface escort or the ASCM passes out of the airship

engagement envelope.

An upper bound on the possible number of engagements is generated for the weapons systems by considering the physical limitations associated with the systems just described verses the threat parameters and the cutoff criterion. The variable input factors are:

a. ASCM and SAM velocities

b. ASCM and Radar heights above water (for determination of the range of target detection and the open fire range of the AAW escort)

c. the maximum number of missiles in flight

d. the number of launchers and their reloading time

e. the number of illuminators available

D. ANALYSIS

An electronic spreadsheet application has been created to allow evaluation of impact of varying the above parameters of interception (see Appendix A, p. 102, for details on spreadsheet implementation). The result is a complete time sequenced record of events from the raid crossing the appropriate weapons systems radar horizon and extending to the last ASCM's arrival.[3] Only simple interception geometries are considered. The raid is an undefined stream with the target spacing set so as to provide the raid duration desired. No particular assumption is made as to the "shape" of the raid. As far as the model is concerned, the ASCMs could be inbound from sixty different directions. For a raid of 60 ASCMs of 1 minute duration, target spacing (interarrival time) is 1 second. If tactical aircraft are required to close to within engagement range to target and fire ASCMs, a limitation no more than 2 missiles per aircraft is imposed. The 2 missile restriction then requires 30 tactical aircraft

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[3]The spreadsheet used in this analysis is a deterministic calculation of the saturation limit of the weapon systems modeled. Most advanced spreadsheet generators including the one used here, have a random number generation capability. With very slight modification to the listing in Appendix A, a complete discrete event Monte Carlo simulation is possible. This assumes, of course, the user has valid probability distributions for the input parameters.

with a 2 second spacing to deliver the raid of 1 minute duration. The 2 missile limit is only a constraint on the airship/NTU ship performance.

The electronic spreadsheet output is examined to determine when any "criterion" (see page 57) for the particular scenario has been violated. It should be noted, on any particular run, several criteria may have been violated, each at different number of intercept opportunities. By design of the program, the values determined from the spreadsheet output in surface-ship-only scenarios are equivalent to the value of the single AAW ship (SAS) Performance calculated by (EQ. 2) in the AAW effectiveness model. The successful engagements generated in airship assisted scenarios are used to reduce the raid size in the effectiveness model.

1. Generation Of Model Input For Airship Performance (When Combined With Older AAW Escorts)

For the preliminary analysis 2 airship configurations are considered. The first configuration is the same as used in the convoy analysis, that of an airship with 2 AWG-9 systems. The second configuration considered will be an airship of increased displacement carrying 4 AWG-9 systems.

The threat scenarios considered in the airship supported engagements include the "reasonable near term" threat characteristics as well as threats which are entirely theoretical, in that no regard has been given to the physical plausibility of the particular combinations of ranges and speeds. We wish merely to establish what are likely to be the broad bounds of airship performance. Table 9 shows the basic results of 18 different threat variations. These variations range from 30 Mach 1 aircraft, firing 60 Mach 1 ASCMs at 30 nm over 1 minute, to 60 Mach 3 ASCMs, launched in excess of 150 nm., with zero second spacing, against 3 airship (2 illuminator)/escort combinations (output, representative of many of the scenarios, will be found in Appendix A, p. 119). Table 9 lists the expected number of surviving cruise missiles to be faced by the area defense AAW force after "filtering" by the 2 illuminator airship.

TABLE 9

ASCMS EXPECTED TO SURVIVE TO AAW INNER DEFENSE ZONE
(When 2 Illuminator Airship Is Employed)

Outer Defensive Zone Configeration:	1 Airship 1 AAW Ship 1 Launcher 2 Rails 6 Tracks 12 SAMS	1 Airship 1 AAW Ship 2 Launchers 4 Rails 6 Tracks 12 SAMS	1 Airship 2 AAW Ships 4 Launchers 8 Rails 12 Tracks 24 SAMS
Threat: 30 A/C @ M1, 2 sec interval with:	Expected Surviving ASCMs		
60 ASCMS @ M1 60 nm launch	45	32	29
60 ASCMS @ M2 60 nm launch	46	41	35
60 ASCMS @ M3 60 nm launch	46	42	36
60 ASCMS @ M1 30 nm launch	36	21	12
60 ASCMS @ M2 30 nm launch	38	24	14
60 ASCMS @ M3 30 nm launch	38	24	14
30 A/C @ M1, 0 second interval with:			
60 ASCMS @ M1 60 nm launch	45	38	33
60 ASCMS @ M2 60 nm launch	45	43	38
60 ASCMS @ M3 60 nm launch	46	44	39
60 ASCMS @ M1 30 nm launch	46	35	15
60 ASCMS @ M2 30 nm launch	48	37	17
60 ASCMS @ M3 30 nm launch	39	37	17
OTH ASCMS, 1 second interval			
60 ASCMS @ M1	46	43	32
60 ASCMS @ M2	52	50	49
60 ASCMS @ M3	55	52	53
OTH ASCMS, 0 second interval			
60 ASCMS @ M1	47	43	38
60 ASCMS @ M2	52	51	50
60 ASCMS @ M3	55	54	54

Assumptions: single SAM P_K is 0.5, 2 SAM salvos, targets are at 25 ft., airship and NTU escort(s) are essentially co-located, airship altitude is 10,000 ft.

In the case of the 2 illuminator airship, when working with a single launcher AAW escort, the reload time of the surface ship and the limited number of airship illuminators are the controlling factors in the number of engagements possible. When the 2 illuminator airship is linked to a double launcher configured surface escort, effectively reducing the inter-salvo time by half, the number of ASCMs surviving to engage the surface escort screen is only slightly decreased. The controlling factor for the engagement is the number of illuminators and illuminator availability. By comparison, Table 10 shows the additional 30 to 40% threat reduction expected from a 4 illuminator airship compared to the 2 illuminator airship.

TABLE 10

REDUCTION OF ATTACKING FORCES EXPECTED WITH 2 AND 4 ILLUMINATOR AIRSHIPS
(Airship Linked With 2 NTU Escorts)

Airship with:	2 Illuminators:	4 Illuminators
% Reduction		
Long range ASCMs	47	75
Medium range ASCMs (< 60 nm)	40-52	78
Short range ASCMs (<30nm)	72-75	100
Aircraft penetrating to 60 nm	35	58
Aircraft penetrating to 30 nm	60	95-100

Based on Table 9 scenarios where the maximum velocity for long and medium range low flying ASCMs was, respectively, Mach 1 or Mach 2.
Assumptions: Escorts provide a total of 4 twin rail launchers, a single SAM P_k of 0.5, 2 SAM salvos, targets (30 aircraft and or 60 ASCMs) are at 25 ft., airship and NTU escort(s) are essentially co-located, airship altitude is 10,000 ft.

2. Generation Of Model Input For AAW Escort Performance

The next level of assessment evaluates how well the "state of the art" and "updated old ship" will perform in the face of the proposed threat in a stand alone mode, i.e., without airship based surveillance and fire control systems. For the sake of brevity, the threat scenarios will be reduced from the theoretical, to the plausible near term threat. With regard to plausibility, Mach 3 and Mach 2 "sea skimming" ASCMs will be allowed to stretch the upper bound but will be limited to launch ranges on the order of 30 and 60 nautical miles, respectively. With these constraints in mind, the capability of the surface fleet to deal with the threat is examined.

Over the range of reaction times and reload times assumed for the "Older AAW escorts" very little capability exists against low flying ASCMs even at the most optimistic threat levels. Based on this, older AAW escorts are dropped from the analysis *in a stand alone role*. For state of the art AAW escorts, Tables 11 and 12 are a compilation of the saturation limits of the unassisted surface escort spreadsheet scenarios, when the escort is using a Mach 2.5 SAM with an 8 second illuminator scheduling interval. Cruise missiles, 1 second apart, at an altitude of 25 feet are used for the scenarios in Table 11 while missiles at an altitude of 6 feet are used in Table 12. The results obtained are averaged between the 8 second and 10 second time of flight criterion and the results plotted in Figures 15 and 16 for the 25 foot and 6 foot ASCM heights respectively. The results are then averaged between the 25 and 6 foot ASCM heights. The process has been repeated for Mach 2 and Mach 3 SAMs with the results plotted as the average performance of the state of the art AAW escort, with the SAM performance indicated, in Figure 17. The values from Figure 17 are then used as the AAW escort input into the effectiveness model as the values for (EQ. 2). Figure 18 presents the results of repeating the entire above process for the ten to 12 second minimum time of flight criterion.

TABLE 11

ASCMS REQUIRED TO SATURATE "State of the Art" AAW ESCORTS
(ASCMs at 25 feet)

Number of ASCMs **Engaged** ***Prior*** to **Saturation**

Constraint Violated	Threat @ Mach 1	1.5	2.0	2.5	3.0
	Reaction Delay = 10 seconds				
TOF< 8	30+	28	20	10	8
TOF< 10	30+	20	12	8	4
	Reaction Delay = 15 seconds				
TOF< 8	30+	24	16	6	2
TOF< 10	30+	20	12	[illegible]	0
	Reaction Delay = 20 seconds				
TOF< 8	30+	24	12	4	2
TOF< 10	30+	16	8	0	0

Assumptions: 60 ASCMs, Over the Horizon launch, 1 second spacing. Escorts with vertical launch, Mach 2.5 SAMs, illumination scheduled at 8 seconds.

TABLE 12

ASCMS REQUIRED TO SATURATE "State of the Art" AAW ESCORTS
(ASCMs at 6 feet)

Number of ASCMs Engaged *Prior* to Saturation

Constraint Violated	THREAT @ Mach 1	1.5	2.0	2.5	3.0
	Reaction Delay = 10 seconds				
TOF< 8	30+	20	12	8	4
TOF< 10	28	12	8	4	2
	Reaction Delay = 15 seconds				
TOF< 8	30+	20	12	6	2
TOF< 10	24	12	4	2	0
	Reaction Delay = 20 seconds				
TOF< 8	28	16	8	4	2
TOF< 10	20	8	4	0	0

Assumptions: 60 ASCMs, Over the Horizon launch, 1 second spacing. Escorts with vertical launch, Mach 2.5 SAMs, illumination scheduled at 8 seconds.

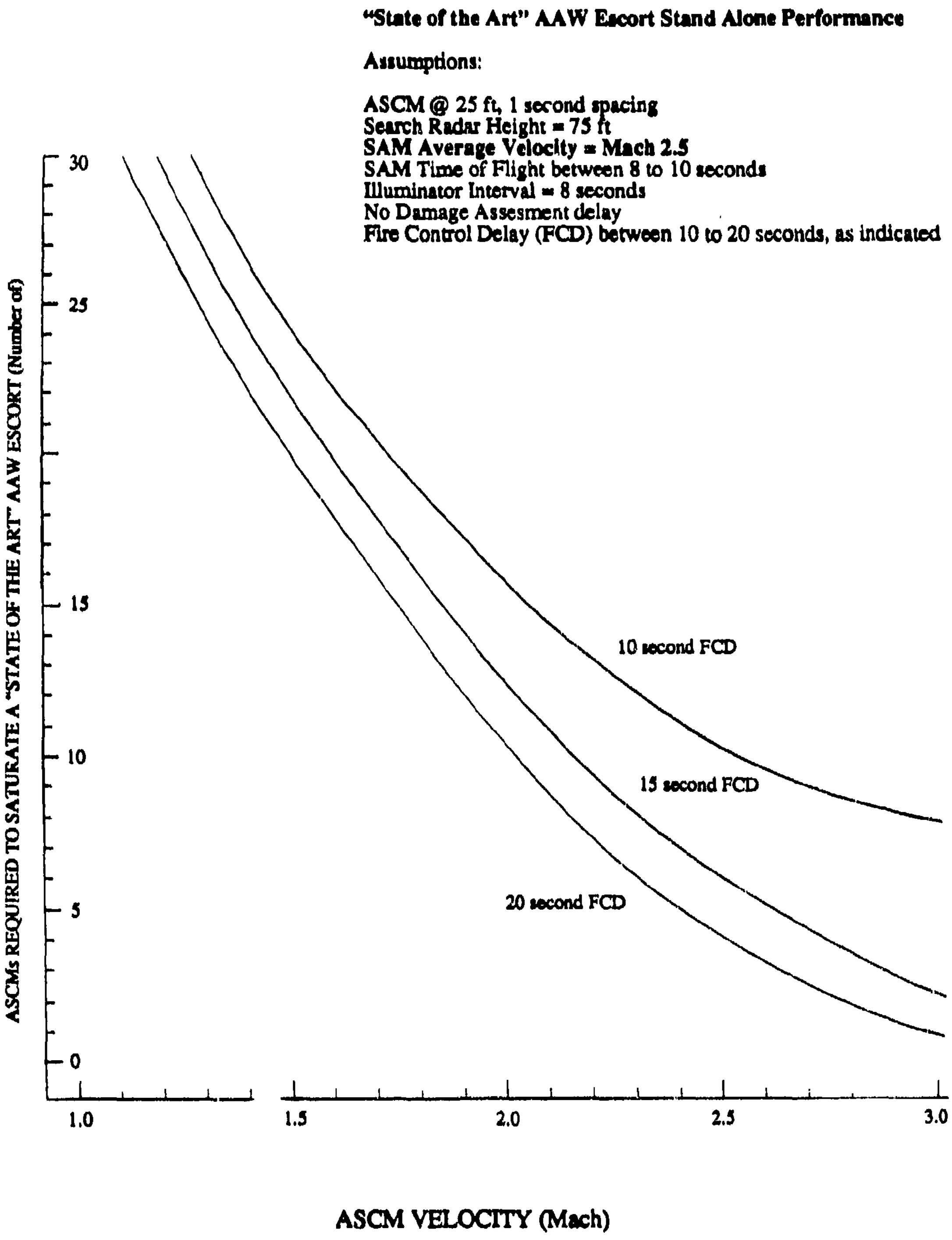


Figure 15. Saturation Level for AAW Escorts Against ASCMs at 25 feet

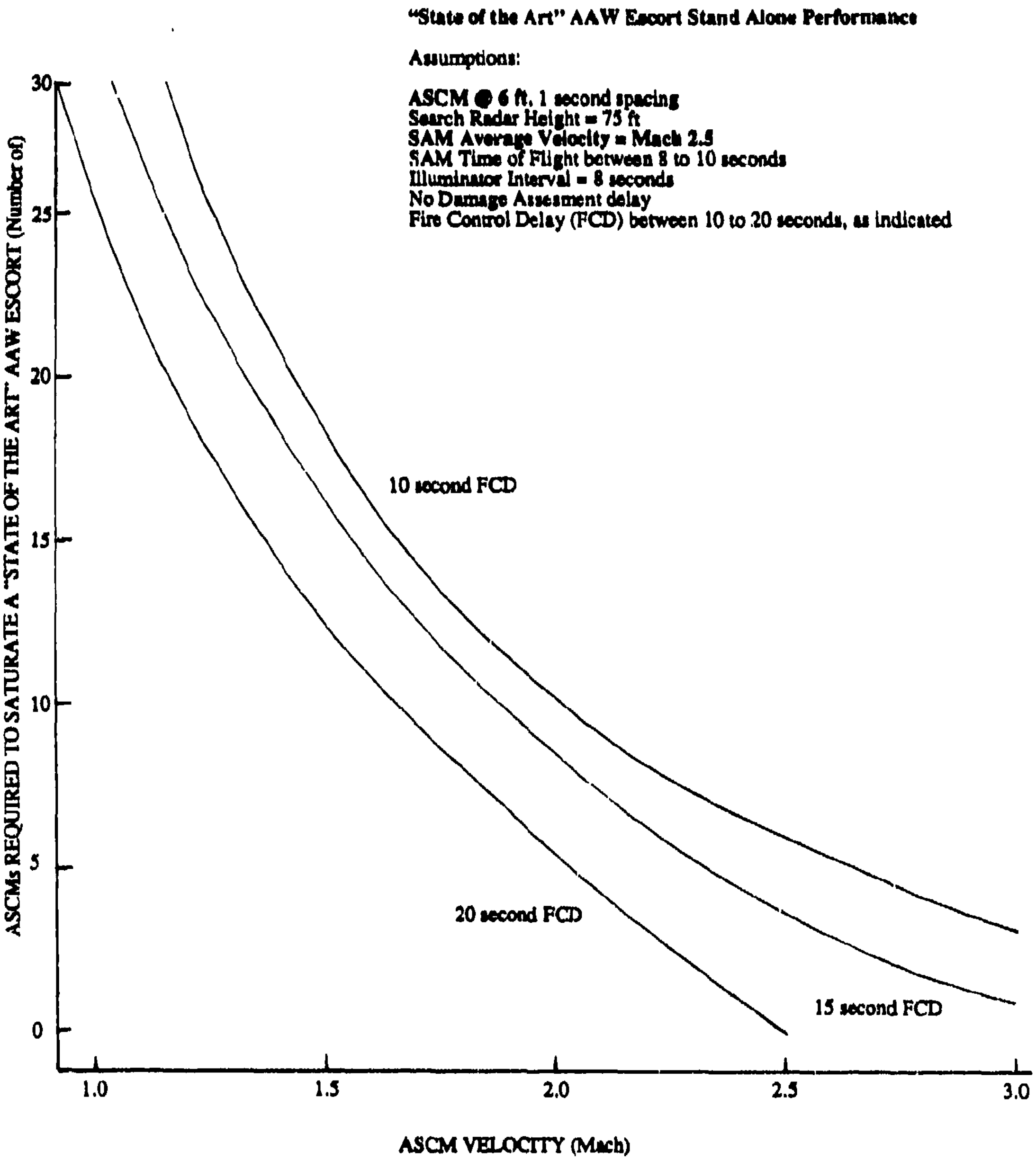


Figure 16. Saturation Level for AAW Escorts Against ASCMs at 6 feet

AVERAGE "STATE OF THE ART' AAW ESCORT STAND ALONE PERFORMANCE BASED ON SAM AVERAGE VELOCITY
ASSUMPTIONS:
Search Radar Height = 75 feet
SAM AVERAGE VELOCITY as Indicated
Illuminator Interval = 8 seconds
ASCM Height bnetween 6 to 25 feet
SAM time of flight between 8 to 10 seconds
Fire control delay between 10 to 20 seconds
No damage assessment delay (SAM P_k = 1)
ASCM interarrival spacing = 1 second

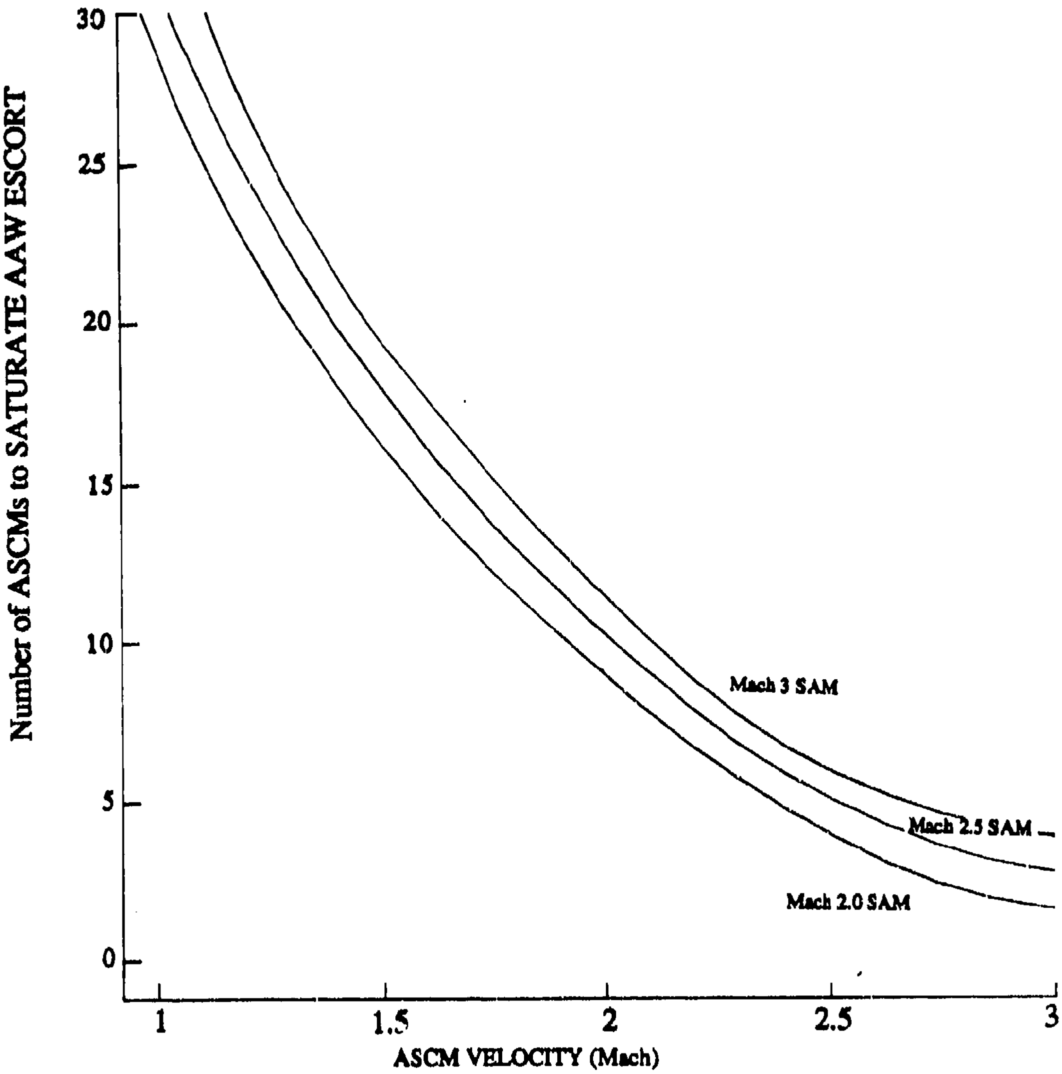


Figure 17. Average Saturation Level for AAW Escorts Utilizing 8 Second Illuminator Scheduling

State of the Art Escorts

Search Radar Height = 75 ft
SAM Average Velocity = Mach 2.5, by 5 nm
SAM Time of Flight between 8 to 10 seconds
Fire Control Delay (FCD) between 10 to 20 seconds
NO DAMAGE ASSESMENT Delay (SAM P_K = 1)
ASCMHeight between 6 to 25 feet
ASCM interarrival spacing = 1 second

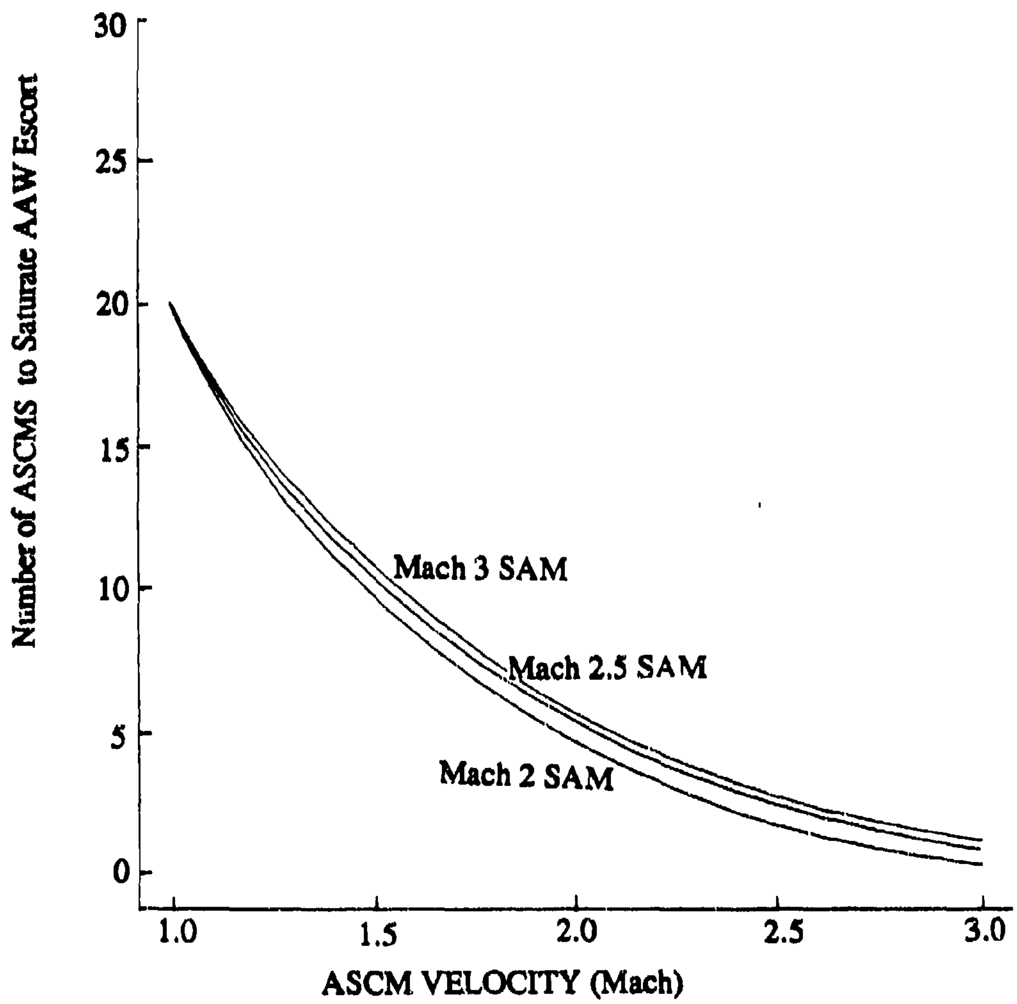


Figure 18. Average Saturation Level for AAW Escorts Utilizing 10 Second Illuminator Scheduling

Examination of data indicates the illuminator constraints found in the previous airship results, also predominate in the surface escort case. The net result, due to the limited time available to counter ASCMs at a 1 second spacing, is the AAW ship suffers a serious decline in firepower at threat velocities above Mach 1.5, across a wide variation of SAM velocities, reaction times and illuminator schedules.

E. RESULTS OF ANALYSIS FROM THE EFFECTIVENESS MODEL

When the aforementioned (Figures 17 and 18) values for the performance of state of the art AAW escorts are considered, the high sensitivity of AAW escort performance to SAM verses ASCM average velocity is apparent.

Combining the results of first allowing the airship/older AAW escorts to "filter" the 60 ASCM raid with the, more favorable to the state of the art AAW escort, values of Figure 17 results in the comparison, shown in Figures 19 and 20, of the value of adding the airship to the battle group.

1. The Significance Of The Results

Based then on the effectiveness model the following assessments can be made. Assuming a Mach 1.5 or greater ASCM threat, and given the state of the art AAW escort is using either a Mach 2.5 or a Mach 3.0 SAM, the battle group utilizing a 2 illuminator airship requires fewer ship assets than a purely state of the art escort equipped battle group. In terms of escort hulls required, the 4 illuminator airship is equal or superior at all ASCM threat velocities. At threat velocities of Mach 2 or higher, battle groups without the airship/NTU AAW escort team suffer a 3-to-1 disadvantage in escorts required.

2. Impact Of The Model Linearity Assumption

The most striking element of the low flying ASCM threat is the "time compression" effect. A basic assumption of the model is symmetric loading of the defenses. The point of

Assumptions:
ASCM @ 6 to 25 ft, 1 second spacing
Search Radar Height = 75 ft
SAM Time of Flight between 8 to 10 seconds
Illuminator Interval = 8 seconds
No Damage Assesment delay
Fire Control Delay (FCD) between 10 to 20 seconds

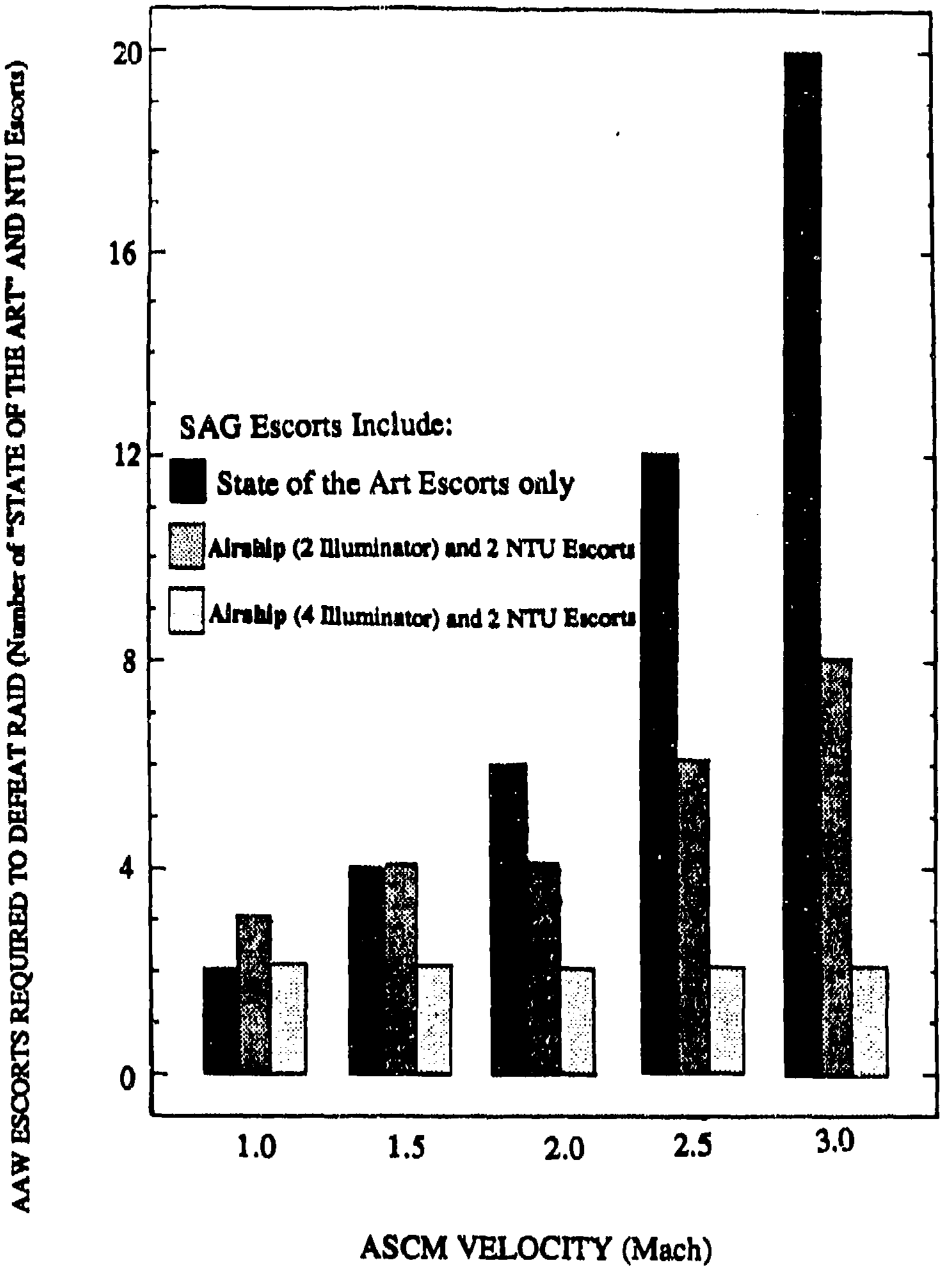
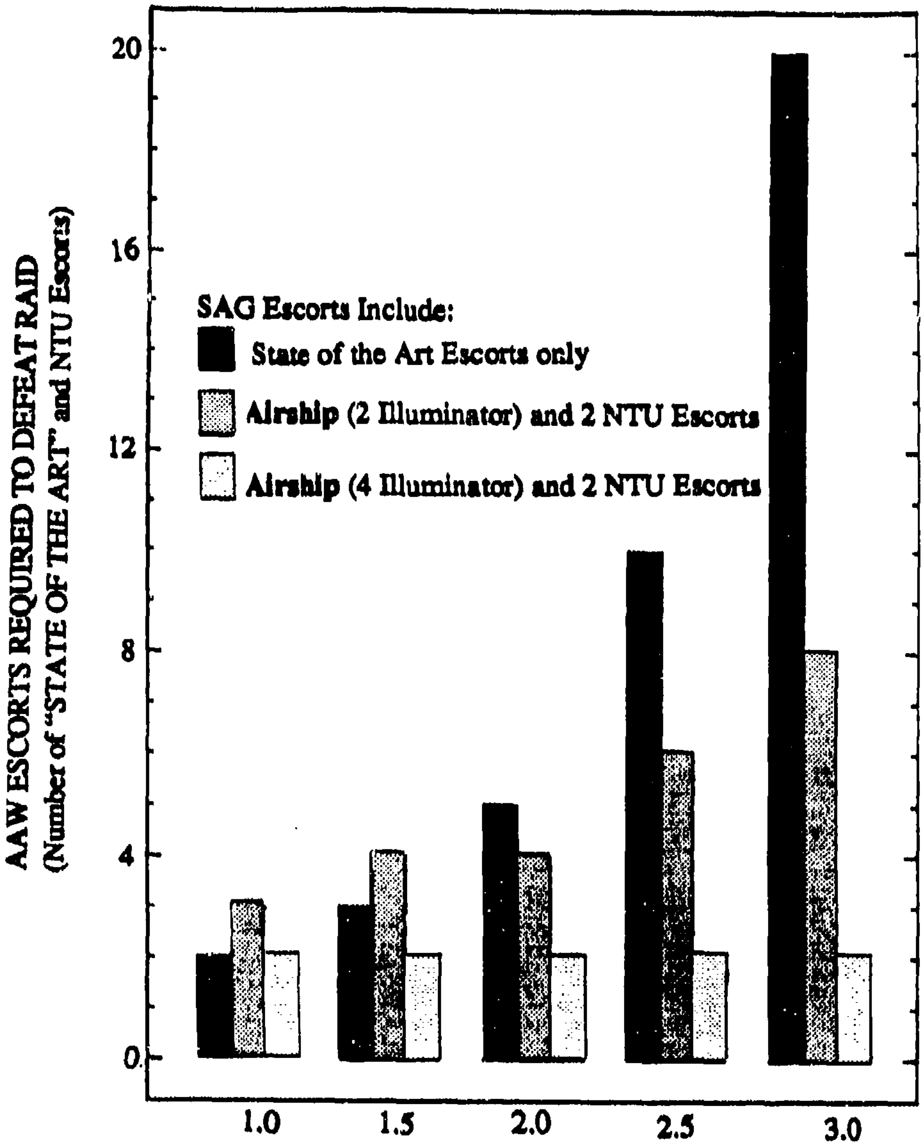


Figure 19. Escorts Required, With/Without Airship, "SOA" Escorts Using Mach 2.5 SAMs

Assumptions:
60 ASCMs @ 6 to 25 ft, 1 second spacing, launched @ 30 nm

State of the Art Escorts

Search Radar Height = 75 ft
SAM Average Velocity = Mach 3.0, by 5 nm
SAM Time of Flight between 8 to 10 seconds
Illuminator Interval = 8 seconds
No Damage Assesment delay
Fire Control Delay (FCD) between 10 to 20 seconds



ASCM VELOCITY (Mach)

Figure 20. Escorts Required, With/Without Airship, "SOA" Escorts Using Mach 3.0 SAMs

low flying missiles is aimed specifically at invalidating this assumption in the "real" world. In the case of high flying high speed missiles, the defending ships have the opportunity to interact so as to prevent any single ship from having to deal with a disproportionate percentage of the raid. The high flyer affords the opportunity of several minutes in which to bring all defenses to the highest state of readiness, to make target assignments, to make assessments of engagements and to re-engage as required. The low flying ASCM seriously limits the battle group ability to perform these basic tasks. A high flying raid of 60 missiles would be revealed several hundred miles prior to its arrival. Assuming a compact disposition of AAW ships of 10 to 20 nm, the time difference between disclosure of the raid to the first ship to disclosure to the last ship in the group, would be 1 or 2 minutes. In the case of the low flying missile, the time difference between the first ship detecting the raid and the next nearest ship would only be the matter of a few seconds. These few seconds against a low flying raid are potentially more significant than the entire first-to-last differential of the high flying raid. No matter the launching mode or range, the high speed ASCM is the most stressful. The only practical near term methods of delivering the Mach 3 sea skimmer would appear to be close-in aircraft and submarines.

Because the launching rate of submarines is likely to be low (relative to a 1 second spacing), the tactical aircraft is considered the worst case threat. Consider that attack aircraft will use short range ASCMs in a completely different manner than that used in targeting long range low flyers. The short range ASCM missile seeker can be used only to "zero out" the minor firing errors in an essentially straight shot, rather than using the seeker to "search", thus allowing the concentration of weapons at a narrow front. The possibilities or options available to the attacker become critical. The attack leader may elect to make use of a relatively slow and high, fuel efficient flight profile. The limiting factor will be the AAW ship missile envelope to horizon profile. The overall effect will be to dramatically increase the attackers loiter time near the ships. Additional time is gained for the attacker by not

having to maintain high speed while loitering at, 500 feet at 50 nm. The raid may stay well below the surface groups horizon while arching around to an optimal strike position. With the shipboard fire control/search radar at 75 feet, attack aircraft at 500 feet come into view at 38.6 nm. Assuming an instant shipboard reaction when the aircraft pops up, a semi-active homing SAM at Mach 3 will take well in excess of 1 minute to arrive. This gives the attack pilot 45 seconds to scout/probe the victim and more than 30 seconds to gently descend 100 to 200 feet, rendering the SAM useless.[4] Under the same conditions, an aircraft at 250 feet will "pop-up" on shipboard radar at about 30 nm, still more than a minute from a possible intercept. It would seem likely attacking aircraft could deliver a strike with minimal losses. Further options presented by the attacker's position are:

a. the ability to attack from any azimuth
b. operate escort jammers very close to the point(s) of attack(s)
c. bring the standoff jammer in close (40 nm)
d. attack and jam from one direction while attempting to jam the SAM uplink and rear reference signals from the opposite direction.

For the sea skimming ASCM the following additional assumptions must be made, if the linearity assumption of the effectiveness model is to hold:

a. defending ships, at the point of attack, have enough warning to position so as to have all illuminators on the engaged axis.
b. All other defending ships, to be counted as effectively supporting the model assumptions, must have a clear field of fire from the horizon to within 1 nautical mile of the ship(s) at the point of attack(s).

However, even with the assumption of a much improved AAW escort reaction time, the case for the additive nature of AAW area defense is difficult to defend, when sea

[4]In an attack, the aircraft will be forced more deeply into the surface escort's engagement zone. Under such conditions, and assuming the aircraft's speed is less than approximately 0.85 Mach, the attacker will have nearly the same time available as the scout, but the post launch maneuvers required for SAM avoidance could not be described as "Gentle". As the attacker is forced to use a higher velocity, to limit exposure to airship directed SAMs, his vulerability is much increased.

skimming ASCMs are delivered at close range by low flying tactical aircraft. The physical position of each ship's illuminators is frozen (time to unmask) by the short duration of the attack. In addition, the forward escorts will tend to screen the raid from the rearward units and a clean field of fire cannot be guaranteed. In a word, a model which contains an implict assumption of a linear or additive characteristic in AAW defense must also be considered to have an implied assumption of a high altitude threat or at least the assumption that the low flying threats are launched at such a range so as to require a substantial "search", producing a random, broad distribution of the threat across the AAW defensive area. At best then, the effectiveness model is quite conservative in describing relative airship effectiveness, when the attack on the battle group is by tactical aircraft.

F. ADDITIONAL AIRSHIP EFFECTIVENESS MEASURES

It is clear the vulnerability of the surface escorts is a function of the ASCM arrival interval. If the ASCMs arrive at an interval of 3 seconds or more, 2 to 4 "state of the art" AAW escorts with Mach 3 SAMs will handle the entire 60 missile raid. The vital question is how the surface battle group may influence the raid interarrival interval. Rather than consider the 1 second ASCM arrival interval as the most severe threat, consider it the best that can be hoped for while being attacked, at close range, by an enemy who intends the ASCM interarrival interval to be zero. Here it is seen, the surface battle group can have no influence on the arrival interval, the outcome is dependent only on the enemy's execution. The past decisions by the opposition on weapons procurement and pilot training, as conditioned by environmental influences at the moment of attack, will decide the actual distribution of ASCMs seen by the AAW area defenses. With this in mind, the saturation data is re-examined against a parameterized enemy probability of success.

The value obtained for an individual ship's saturation limit is considered, with the addition of 1 ASCM, as the number of ASCMs the opposition must attempt to launch in order

to achieve one "mission kill" against the surface battle group. The number of missiles required for a single opportunity is divided into the 60 missiles available in the raid. If the enemy has a given probability of converting an attack opportunity into at least the 1 second arrival rate of ASCMs while attempting a zero interarrival interval, then the probability of successful conversion times the number of possible opportunities gives the expected number of "kills". Figures 21 and 22 show the results of the above calculations when the enemy skill level and environmental conditions give a successful probability of conversion from 0.1 to 0.75. The assumption is the AAW escorts have either a Mach 2.0 or 2.5 SAM. If the number of escorts is 8, then even with Mach 1.5 ASCMs, the opposition can expect to score a mission kill on a battle group ship on every raid. Considering the low expected attrition rate of enemy attack aircraft, if the opposition has the missile assets, several raids could reduce the battle group to the extent to preclude carrying out the primary mission task.

By introducing the airship the number of expected mission kills is dramatically reduced. Figure 23 reconsiders the scenario for state of the art AAW escorts with Mach 2.5 SAMs supported by a 2 illuminator Airship and 2 NTU escorts. Note the 2 illuminator airship significantly reduces the probability that any escort suffers a mission kill. One additional curve is added to Figure 23 to represent increasing the airship illuminators to 4. With 4 illuminators, the expected number of ships subjected to a mission kill, by a tactical aircraft raid, drops to zero.

Two additional aspects of the raid when an airship is used have to be considered. The first is the ability of the airship to interfere with the enemy's ability to achieve the 1 second ASCM spacing. With harassing fire certain from 100 nm in to the launch point, the attacker will want to spend as little time as possible in the area. The ensuing high speed transit will burn fuel at an elevated rate. The higher rate of fuel consumption will have an adverse effect on the time the attacker has available to exercise the command and control functions required to coordinate an attack with a high probability of success. The second additional aspect is the level of attrition indicated for the attacking aircraft. Even considering the variance of the

Mission Kills Suffered by SAG Given the Enemy Probability (P_C) of Acheiving an ASCM Spacing of 1 Second or Less

Assumptions:

Those of Fig. 17 for ASCMs verses Mach 2.0 SAMs

Additional Assumptions:

Attack opportunities are determined by dividing 60 ASCMs by the Escort Saturation Level of Fig. 17 plus one additional ASCM

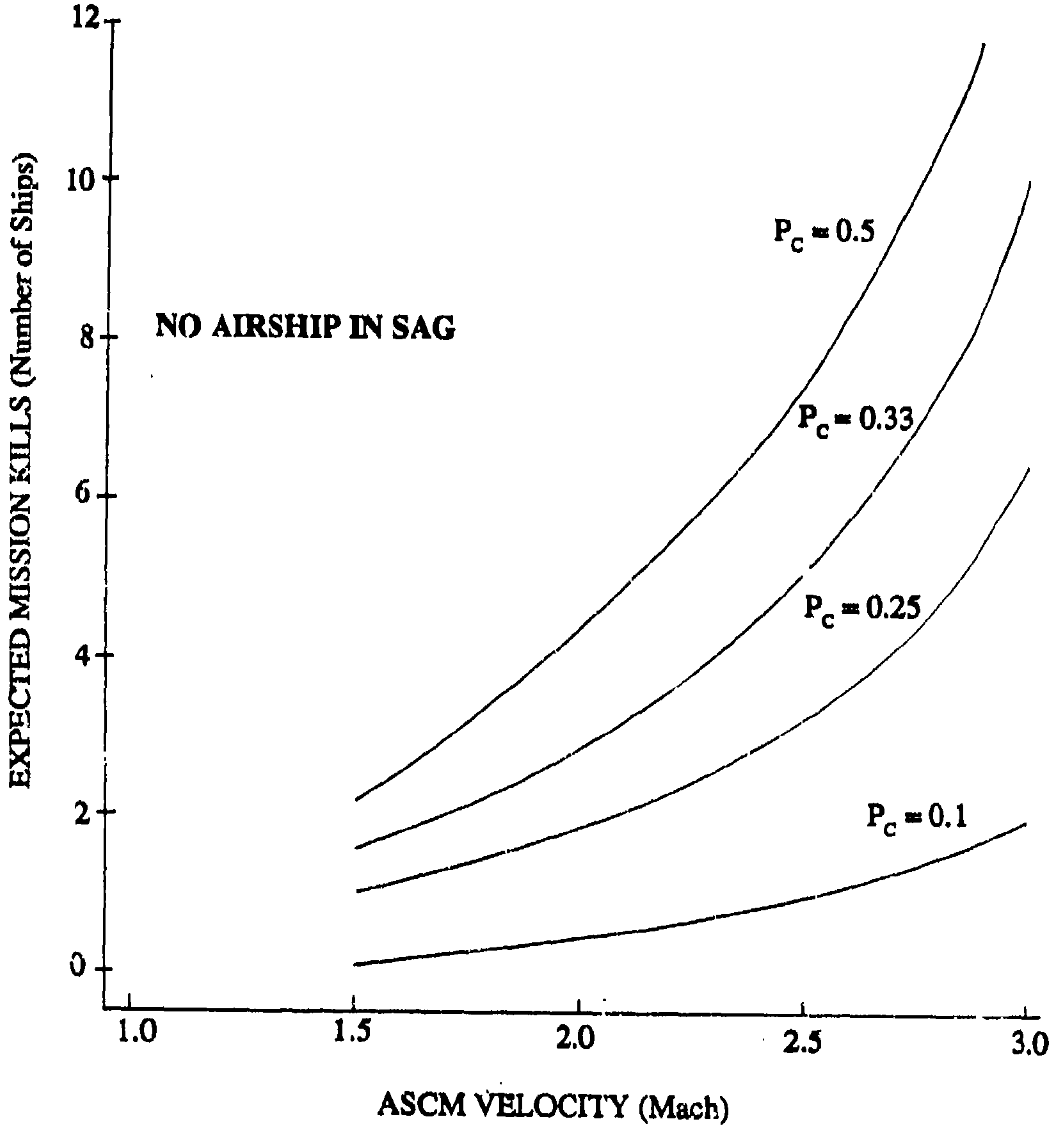


Figure 21. Expected Mission Kills with Mach 2.0 SAMs Against a 60 ASCM Raid

ASCM VELOCITY (Mach)

Mission Kills Suffered by SAG Given the Enemy Probability (P_C) of Acheiving an ASCM Spacing of 1 Second or Less

Assumptions:
Those of Fig. 17 for ASCMs verses Mach 2.5 SAMs
Additional Assumptions:
Attack opportunities are determined by dividing 60 ASCMs by the Escort Saturation Level of Fig. 17 plus one additional ASCM

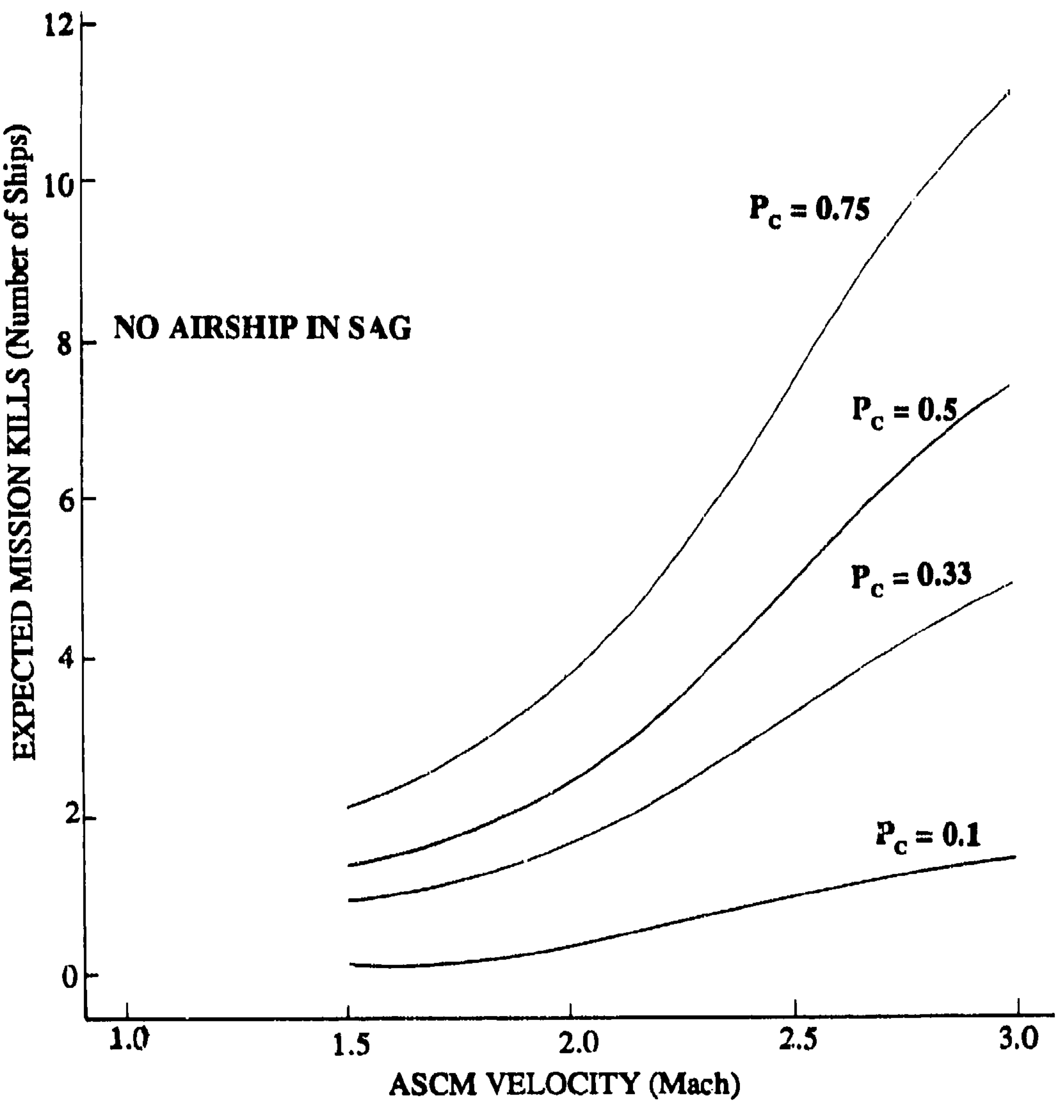


Figure 22. Expected Mission Kills with Mach 2.5 SAMs Against a 60 ASCM Raid

Mission Kills Suffered by a SAG Supported by the Airship/NTU Escort Team, Given the Enemy Probability (P_c) of Acheiving an ASCM Spacing of 1 Second or Less

Assumptions:
Those of Fig. 17 for ASCMs verses Mach 2.5 SAM, State of the Art Escorts
Additional Assumptions:
Attack opportunities are determined by dividing 60 ASCMs by the Escort Saturation Level of Fig. 17 plus one additional ASCM

2 ILLUMINATOR AIRSHIP @ 10,000 ft, 2NTU Escorts with Mach 3 SAMs

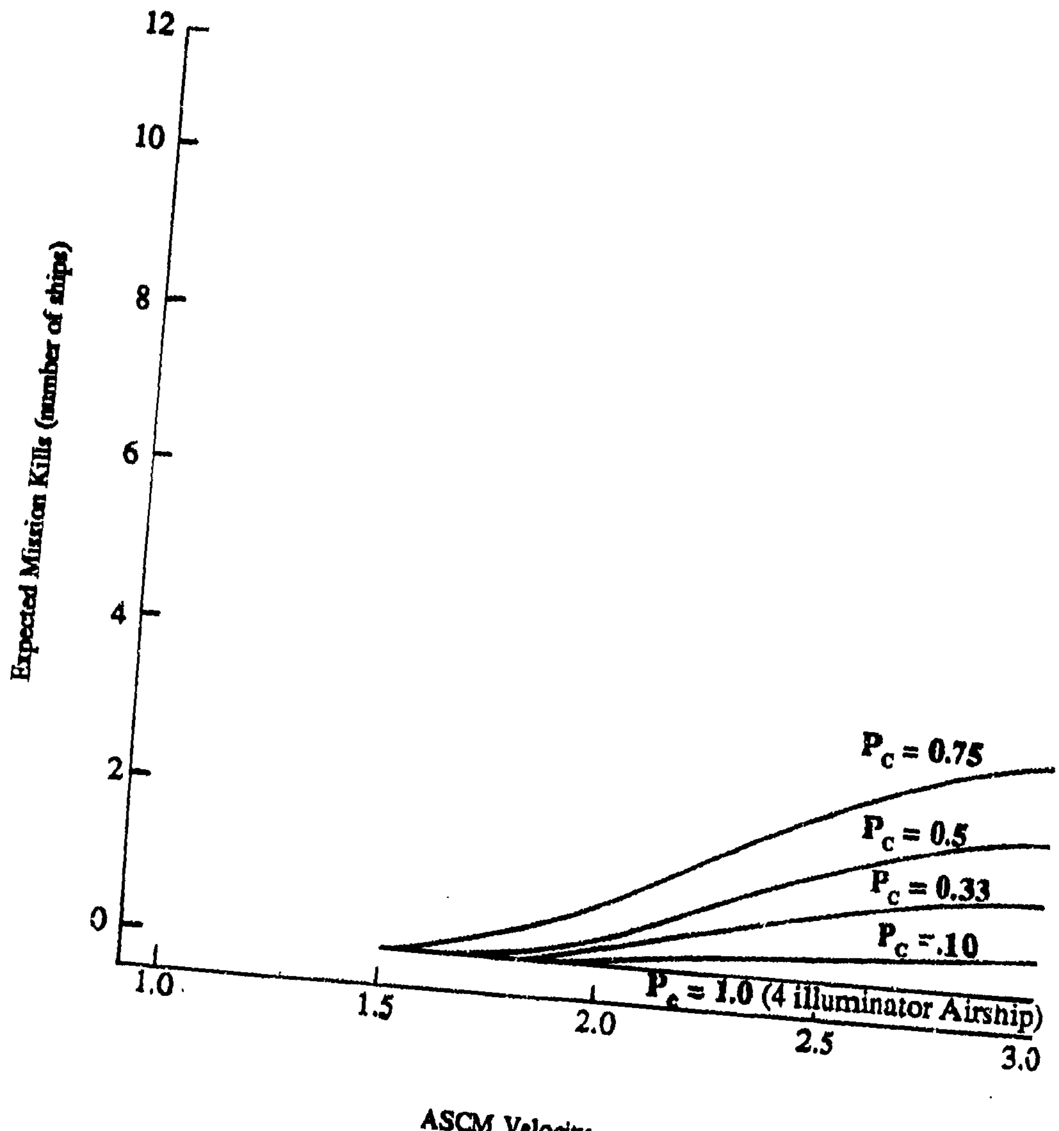


Figure 23. Expected Mission Kills in a SAG with Airships

model, the losses reduce the probability of re-attack dramatically.

This assessment indicates the addition of an airship in a surface force will reduce the expected number of casualties to first line AAW ships to a level at which the primary mission accomplishment is not at risk to attack aircraft. Among the threats, the airship is most effective when dealing with aircraft, primarily resulting from the multiple kill effect achieved by interceptions on attacking aircraft prior to their reaching the ASCM launch point. Long range ASCMs and the effect of more adverse assumptions are examined in the sensitivity analysis following.

G. SENSITIVITY ANALYSIS

The most significant factors controlling the firepower of the airship/NTU escorts are the altitude of the airship, the number of target illuminators, the range of the SAM employed and the constraints of the number of SAMs in flight. The number of SAMs in flight is controlled by the maximum number of missiles supported by the overall fire control system (i.e., the combined airship/NTU escort system) and the firing rate of the escort ships.

The intercept opportunities for 3 airship configurations with 4, 6 and 12 illuminators respectively, have been generated for airship operating altitudes of 10,000, 5,000 and 2,000 feet. The results are shown in Table 13.

From Table 13 it can be seen that increasing the number of illuminators from 4 to 6 only increases firepower slightly and further increases from 6 to 12 illuminators offers no increased firepower. This result develops from the fact that the maximum number of missiles in flight is reached very early in all 3 cases. Because the time of flight of the SAM's is very long compared to the 30 second terminal engagement phase, 12 illuminators show no utility over 6. The value of 12 illuminators would start to increase, in the scenarios, as the length of the terminal engagement phase increased or if the scenario were extended to allow the airship to count short range interceptions after the time of arrival of the first ASCM.

TABLE 13

AIRSHIP/NTU ESCORT ASCMS INTERCEPTION OPPORTUNITIES
(Dual SAM Salvos)

	Airship Configuration 4 Illuminators	6 Illuminators	12 Illuminators
Threat:	Airship @ 10,000 feet		80 second delay
30 A/C with ASCMs @ 30 nm.	42	46	46
30 A/C with ASCMs @ 60 nm.	24	24	24
60 Mach 1 ASCMs	60	60	60
60 Mach 2 ASCMs	24	32	34
60 Mach 3 ASCMs	12	18	26
	Airship @ 5,000 feet		30 second delay
30 A/C with ASCMs @ 30 nm.	30	30	34
30 A/C with ASCMs @ 60 nm	8	12	12.
60 Mach 1 ASCMs	52	60	60
60 Mach 2 ASCMs	20	28	28
60 Mach 3 ASCMs	8	16	20
	Airship @ 2,000 feet		30 second delay
30 A/C with ASCMs @ 30 nm.	16	20	20
30 A/C with ASCMs @ 60 nm.	0	0	0
60 Mach 1 ASCMs	28	28	28
60 Mach 2 ASCMs	10	14	14
60 Mach 3 ASCMs	5	8	8

Assumptions: ASCMs at 1 second spacing, aircraft at 2 second intervals, 2 NTU AAW escorts with Mach 3 SAMs, linked to airship.

The effect of lowering the airship operating altitude reduces the airships radar horizon, in turn reducing the range of detection and earliest possible interception. In descending from 10,000 to 5,000 feet, the radar horizon is reduced from approximately 130 nm to 95 nm. This reduction in operating altitude results in the earliest possible interception being reduced from 88 nm to 67 nm with the assumed Mach 3 SAM (30 second delay). This result would also hold if the maximum range of the available SAM were on the order of 70 nm vice the 100 nm range assumed in the scenarios. The effect on firepower of reducing the airship operating altitude is strong, but not as strong as might have been thought. Reducing the operating altitude by half reduces firepower by about one third. With any of the airship illuminator configurations, descending from 10,000 to 5,000 feet still allows for engagements on all of the 30 aircraft closing to 30 nm while allowing for engagements on a third of the 30 aircraft closing to 60 nm. The most significant effect is seen in the descent from 5,000 to 2,000 feet. Although a majority of aircraft closing to 30 nm are still brought under fire, the airship would have no capability on aircraft launching an attack from 60 nm. Assuming aircraft at 60 nm can launch Mach 2 capable ASCMs, the number of airships and NTU escorts would have to increase by a factor of 3 to adequately deal with the threat.

Under the restrictions imposed in the scenario's, 2 NTU escorts are required to achieve maximum firepower. The maximum capabilities of 2 NTU escorts are not being reached. With the assumption of 4 dual rail launchers with reload times between 25 and 35 seconds, the combined system is capable of launching a SAM every 3 to 5 seconds. The constraint of dual SAM salvos, in the scenarios, was designed to ensure a reasonable probability of kill at the long ranges where the kinetic energy of the SAMs would be low and the uncertainty due to system measurement errors would be high. Clearly, as the range from the airship to the target decreases, the need for dual SAM salvos also decreases. In Table 14 the restriction to dual SAM salvos is relaxed for the 5,000 and 2,000 foot operating altitudes. The maximum number of SAMs in flight remains 24.

TABLE 14

AIRSHIP INTERCEPT OPPORTUNITIES WITH SINGLE SAM SALVOS

	Airship @ 5,000 feet 4 Illuminators	6 Illuminators	12 Illuminators
Threat:			
30 A/C with ASCMs @ 30 nm.	32	56	60
30 A/C with ASCMs @ 60 nm.	8	18	24
60 Mach 1 ASCMs	52	60	60
60 Mach 2 ASCMs	20	30	60
60 Mach 3 ASCMs	0	18	44

	Airship @ 2,000 feet 4 Illuminators	6 Illuminators	12 Illuminators
30 A/C with ASCMs @ 30 nm.	16	30	30.
30 A/C with ASCMs @ 60 nm.	0	0	0
60 Mach 1 ASCMs	28	43	60
60 Mach 2 ASCMs	10	18	40
60 Mach 3 ASCMs	6	10	20

Assumptions: ASCMs at 1 second spacing, aircraft at 2 second intervals, 2 NTU AAW escorts with Mach 3 SAMs, linked to airship, 30 second fire control system delay.

As a result of shifting to single SAM salvos, firepower at the closer ranges, assuming the engagement Pk remains the same, is greatly enhanced with either 6 or 12 illuminators. However, no significant increase in firepower is seen in the 4 illuminator case because illuminator tie-up has become the controlling factor. With 6 or 12 illuminators and the airship operating at the 2,000 foot level, the airship/NTU escort team can be expected to significantly reduce the threat to the SAG.

1. Airship Survivability

Based on the large visual signature and relatively slow speed of the airship, it could argued that airships would be too vulnerable to be useful in combat. It might be simple to just fly in and gun down the airship at close range. This argument does not give close consideration to the capabilities of the modern "state of the art" AAW escort. When such an escort is not plagued, as it has been in this study, by low-flying ASCMs the firepower generated is unequaled. The airship operates in airspace which is the prime killing ground for modern AAW area defense escorts. As a comparison, a scenario is proposed where the opposition chooses to use 20 of its 60 missiles to attack the airship while allotting the remaining 40 to high velocity, aircraft launched ASCMs. Assume the theoretical Anti-Airship Cruise Missile (AACM) has solved the unique airship targeting and fusing problems [Ref. 26:pp. 60-63]. Also assume the AACMs are "locked on" and launched from long range (+200 nm), with an average velocity of Mach 2.5. The defensive situation is assumed to be a 4 illuminator airship at 10,000 feet and 2 NTU escorts accompanying 4 "state of the art" escorts all using long range Mach 3 SAMs. The results from this scenario are that the combined "state of the art" escorts (40 second delay, see Appendix A, p. 118 for other assumptions) achieve a DOF of 4 on every anti-airship missile prior to the first such missile coming within 50 nm of the airship, while the airship/NTU escort combination (with a 0.5 single SAM probability of kill) destroy all of the other 20 attacking aircraft! Of all of the threats faced by a surface force, 3 of the most significant are of no threat to the airship. These threats being, low-flying ASCMs, torpedoes and mines. Based on these considerations, and its defensibility by reason of position, the threat to airship survival, compared to any other unit in the surface force, would have to be considered lower overall.

V. COST ANALYSIS

The objective of the cost analysis is to determine a reasonable estimate of the financial requirements to acquire, operate and maintain the fleet of airships described in the convoy and surface action group scenarios, over the 30 year lifetime of the system, so as to allow a comparison of the airship with alternatives. The analysis is broken into the following five main areas:

a. The costs of acquiring the base line 2.5 mcf airship exclusive of the combat system. The cost estimated covers the airframe or hull, propulsion and flight avionics and associated subsystems to, essentially, create a ready to float vehicle. The combat system or mission payload, which is costed separately, is the air and surface search radars, the fire control radars , communication suite and the associated computers, interfaces, controls and displays required to make the airship "operational".

b. The marginal cost of increasing the size of the hull to accommodate increasing the payload from the 25,000 pounds of the 2.5 mcf airship to 35,000 pounds in the 3.5 mcf airship.

c. Combat system costs, sometimes referred to as mission payload or mission avionics. Costs are estimated for the "common" avionics to be installed in all three variants, then, separate costs are calculated for the fire control system required for two to twelve illuminators.

d. Operating and Support costs for the entire airship system.

e. The cost of support equipment, facilities and initial spares. The above costs are prorated to estimate the life cycle cost of the system.

A. HULL COSTS

In arriving at an estimate for airship costs, a cost estimating relationship developed from historical data by the analysis firm of J.W. Noah and Associates [Ref. 27] is utilized.[Ref. 28] The 1987 U.S.Navy contract with Westinghouse/Airship Industries for an Operational

Development Model airship (ODM) is used, inconjuction with learning curve theory [Ref. 29:p. 93], to validate the J.W. Noah (JWN) C.E.R. The WAI contract called for conducting the research and development, design, construction and testing of one airship displacing 2.3 million cubic feet for a fixed price of $169 million including a $51 million (FY87$) subcontract to Grumman for radar development work. The 1987 contract also made provision for the purchase of up to five additional airship airframes of the same design for a price of $294 million or a single additional airship for $83 million.[Ref. 19:p. 904]

1. C.E.R. For Airship Costs

The J.W. Noah and Associates studies previously referenced, developed the following C.E.Rs for estimating Airship production costs:

a. Initial RTD&E costs will be 2 times the first unit cost

b. Airship Hull costs represent 95% of the total cost with Propulsion and Flight Avionics taking the remainder

c. First unit cost are found from EQ. 1 as:

$Y = 0.000239 \times S^{2.61} \times D^{0.33}$, [EQ. 1]

where,

Y = first unit cost, FY77M$

S = maximum speed, knots

D = air displacement, m.c.f.

$r^2 = .82$, s.e.e = .317

(see Appendix B, p 131 for Predicted vs Actual Costs)

d. the learning curve factor[1] for Hull production is 0.83

Using the WAI contract as a benchmark, the assumption is made that the 5 additional

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[1]Batchelder [Ref. 29:p. 116] lists a mean learning curve of 0.75 for 25 military aircraft, based on 1966 data.

airships allowed for are the first production lots of the 20 airships required in the proposed system. Using this assumption allows use of the cost estimating techniques of Batchelder [Ref. 29:p. 93-120] to work backward to separate the first unit cost from the research, development and test and evaluation costs covered in the initial contract, and then to continue forward to estimate the final production cost of 20 units. The methodology assumes the cost figures used represent the "costs of production". The contract figures, on the other hand, are the costs of production and, assuming WAI is responsible to its stockholders, an unknown amount of profit. To consider the effect of the commingled funds, the following assumptions apply:

a. The initial RDT&E contract for $169 million stands alone ($118 million less radar). The company would prefer to at least break even, but would accept moderate losses in expectation of future profits.

b. The government is not obligated to buy any follow on airships, but at its own option may order from one to five. Under this requirement, the assumption is made that WAI intends to "break even" on their investment on the first or second production unit, otherwise the firm could be locked into a significant loss.

With the above assumptions, the proposed cost estimating relationships, in order to be considered valid, should show the potential for WAI to profit from the 1987 contracts but should not allow for an excessive profit.

2. Airship Costs Based On C.E.R.S

Based on the requirements for a 2.3 mcf airship with a maximum velocity of 90 knots, the JWN estimate, corrected for inflation, results in a first unit cost of $75.16 million in FY87$ [Ref. 30]. The total cost of hull production is found from EQ. 2 [Ref. 29:p. 98] as:

Total Hull Cost = $a\ X^{(b+1)}$, [EQ. 2]

where:

a = first unit Hull Cost

b = Learning Curve factor

X = Hull units produced to date

The resulting cost for producing six hulls is $278.6 million (FY87$). Estimating the propulsion/avionics costs as 5% of hull costs gives a cost of $15 million. Using the factor of two for RDT&E costs over first unit costs results in a RDT&E cost of $150 million. The total cost of producing six "float-away" airships is rounded to $443 million (FY87$). The total funding available for producing the six airships by the WAI contract is $412.4 million (FY87$). The difference, a loss of $30.4 million, is substantial. From the cost of producing six airships by the JWN CERs, it must be assumed either WAI intends to lose a lot of money, WAI has made a technological break through, or one or more of the CERs fail to properly consider a variable. Believing the latter, the JWN estimating relationships are reexamined.

Profitability in the initial WAI contract is strongly influenced by the ratio of RDT&E costs to first unit costs. If the RDT&E ratio exceeds one by a significant amount no profit can be achieved in the WAI contract unless first unit costs are extremely low. JWN concluded that due to lack of airship RDT&E data, the RDT&E ratio of cargo aircraft, on the order of two to one, could be used as an approximation [Ref. 27:p. 6]. The ratio of RDT&E costs to first unit costs used in the above calculation was two. But Lancaster [Ref. 31:p. I-25] counters that the RDT&E cost ratio for airships which do not significantly challenge the state of the art should be on the order of one. The JWN figure relies entirely on complex fixed-wing aircraft costs and includes many designs which challenged the state of the art of their day (the C-5A is listed with a ratio of 2.27) [Ref. 27:p. III-1]. If the ratio of RDT&E to first unit cost is revised downward to one, the cost estimate for the total six airship run is reduced to $368 million.[2] This reduction allows for a before taxes profit of just under 11% on a combined initial and follow on contract. The use of a ratio of one reduces the loss in the initial contract to $32 million.

[2]JWN [Ref. 27:p. 6] attached no statistical significance to the ratio of RD&TE to first unit cost, it is taken as a "rule of thumb". JWN derives the C.E.R. for first unit costs entirely from airship data. As noted, the RDT&E ratio was derived from a separate data source, thus rejecting the JWN RDT&E figure does not result in concluding the C.E.R. for first unit cost is invalid.

The first unit cost of the JWN C.E.R. by a large margin, is driven by the maximum velocity of the airship ($\text{Speed}^{2.61}$). When the causal relationship between speed and cost is considered, an increase in the maximum speed is reflected in a rapid increase in the aerodynamic load the hull must accommodate. The maximum bending moment for gust penetration becomes the driving factor in determining the hull strength for a given velocity. Accounting for additional speed increases the overall weight of the hull [Ref. 32]. By this means, the non-linear increase in hull strength required by increasing the airship's maximum velocity, cost is reflected by speed. However, judged by today's technology the well designed old airships could not achieve the true maximum velocity of which their airfames were capable. The "normally aspirated" engines of all previously constructed airships suffered from a considerable reduction in available horsepower with increasing altitude [Ref. 33]. The modern design considered here, with turbo-charging and gas turbines, suffers comparatively little power loss at altitudes up to 10,000 feet. A modern airship may use the gain in "apparent" horsepower to increase speed in the less dense atmosphere found at 10,000 feet. The net result is a modern airship which achieves a speed of 90 kts. at a 10,000 foot altitude may have insufficient installed horsepower to make 80 kts. at sea level. Based on these considerations, it is inappropriate to use maximum velocity without an altitude correction factor. The proposed airship is then based on a maximum velocity of 82 kts at sea level (82 kts being the design speed of the ZPG-3 airship). With the "altitude corrected" maximum velocity of 82 knots at sea level, the JWN C.E.R. estimates the first unit cost of a 2.3 MCF airship at $58.95 million in FY87$. The airspeed corrected C.E.R. is applied with two variations. In the first instance program costs are estimated with the RDT&E factor at two, and in the second, RDT&E costs are reduced to one times the first unit cost. The results of these calculations are shown in Table 15, along with those from the unmodified JWN C.E.R. and the case where only the RDT&E costs are reduced.

TABLE 15

PRODUCTION COSTS FOR A 2.3 M.C.F.AIRSHIP BY C.E.R.S
(in millions of FY87$)

CASE	A	B	C	D
First unit	75.16	75.16	58.95	58.95
Hull production	278.60	278.60	218.69	218.69
Propulsion	14.90	14.90	10.90	10.90
Total production	293.50	293.50	229.59	229.59
RDT&E	150.32	75.16	117.9	58.95
Total cost	443.82	368.66	347.49	288.54
Inidal single airship contract value				118.20
%Profit (before TAX)	-92.86	-29.31	-51.16	-1.29
Full six airship contract value				412.40
%PROFIT (before TAX)	-7.4	10.61	15.74	30.03
Airship cost (per)	73.97	61.44	57.91	48.09

Notes, adjustments to original JWN C.E.R in column: A, no adjustment, the original JWN C.E.R. used, B, the RDT&E ratio is lowered to one, C, adjusted for maximum airship speed @ sea level, D, the RDT&E ratio is lowered to one, adjusted for maximum airship speed @ sea level of 82 kts. First unit costs are absorbed in hull production.

The modified C.E.R.s all show a potential for profit over the full six airship contract. In no case was any potential profit estimated for the initial contract. Only in the case where both the RDT&E ratio and the airship maximum speed were modified from the original JWN C.E.R.s was the loss on the initial contract small. For use as a bases for comparison against alternative systems the estimate from the speed only (C above) modified C.E.R., with a modest profit of 16%, appears as a conservatively reasonable choice.

B. MARGINAL COST OF INCREASING AIRSHIP SIZE

When the cost estimating relationship (modified for maximum airspeed at sea level) is applied across a range of airship displacements from the basic 2.5 mcf to almost twice as large at 4.6 mcf, costs result as shown in Table 16.

TABLE 16

AIRSHIP COST AS A FUNCTION OF DISPLACEMENT FOR A 21 AIRSHIP BUY
(Costs in Millions of FY87$)

Airship Displacement (million cubic feet)	2.50	3.00	3.50	4.60
First unit	60.59	64.35	67.71	74.10
Hull production	561.35	596.16	627.27	686.47
Propulsion	55.51	63.05	70.58	87.15
Total production	616.86	659.21	697.85	773.62
RTD&E	121.19	128.70	135.42	148.20
Total cost including 20% profit	885.66	945.49	999.92	1,106.19
Airship cost (per unit)	42.17	45.02	47.62	52.68

Note: First unit costs are absorbed in hull production.

C. COMBAT SYSTEM COST

Mission avionics costs are calculated by use of C.E.Rs and learning factors for the AWG-9 fire control system and learning for the AWG-9 modification and installation costs [Ref. 34:pp. 32-45]. A flat rate of $15 million (FY87$) is estimated for the common suite (the

base line S3-B avionics, TPS-63 and NTU components) [Ref. 35].[3] Mission avionics and airship costs are shown in Table 17. Note that the airship cost rises less than 30% as the displacement is doubled, but as the mission avionics payload is increased to the "brute force" level for guaranteed performance, overall costs approximately double.

D. PROGRAM ACQUISITION COSTS

To obtain the total acquisition cost the costs of production and research and development are added to the costs of Investment for:

a. building or conversion of facilities to support the airship

b. improvements to manufacture's facilities

c. initial training of crew and support personnel

d. initial spares

Costs for items (a) through (c) are estimated based on the 1977 study conducted by Goodyear Aerospace for a similar system.[4] The following cost estimates, corrected for inflation to millions of FY87$, are made for a 21 airship fleet.

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[3]The cost of the basic avionics suite is based on estimates from a 1983 Rand study [Ref. 35]. The 1983 study looked at the case for a new development 5000 pound avionics suite using CERs developed in the previously cited [Ref. 34:pp. 32-45] Rand avionics paper. The case for the airship basic combat system avionics is similar. The study concluded that the unit cost of the system would be about $20 million (FY87$). The research and development costs and production costs were approximately equal. Because the airship system is constructed from existing in production hardware, RDT&E costs should be lower. A factor of 0.75, to discount RDT&E, was applied to the Rand figure to estimate the basic airship suite at $15 million in FY87$.

[4]The Goodyear study looked at costs for two airship sizes, 1.5 mcf and 11.5 mcf respectively [Ref. 36:p. 21]. This study used a linear interpolation between the two given sizes for a 3.0 mcf airship.

TABLE 17

MISSION AVIONICS AND TOTAL SYSTEM COSTS

Airship Displacement (million cubic feet)	2.50	3.0	3.50	4.60
Fire Control production factors, (costs in M$)				
AWG-9 units to date	640	640	640	640
AWG-9 first unit cost	17.82	17.82	17.82	17.82
Cost of initial AWG-9 unit for airship	3.51	3.51	3.51	3.51
Illuminators/airship	2	6	12	12
New units installed	42	126	252	252
Install/modification cost per AWG-9	0.70	0.70	0.70	0.70
Mission Avionics, 21 sets GFE in FY87M$				
Production	109.41	323.30	633.43	633.43
Installation	11.51	26.20	44.01	44.01
Total AWG-9	120.92	349.50	677.45	677.45
Base Line Suite	315.00	315.00	315.00	315.00
Total avionics	435.92	664.50	992.45	992.45
Mission avionics per airship	20.76	31.64	47.26	47.26
Total cost for 1 ready airship	62.93	76.67	94.87	99.93
Total R&D and Production for a 21 Airship Buy	1,321.58	1,609.99	1,992.37	2,098.63

a. $60 FY87M$ for facilities to support the airship at NAS Lakehurst and NAS Moffet, including airship peculiar equipment (helium storage and handling, ground support equipment, etc.) [Ref. 36:p. 16]

b. $30 FY87M$ for improvements to manufacture's facilities [Ref. 36:p. 15]

c. $20 FY87M$ for initial training of crew and support personnel [Ref. 36:p. 20]

Initial spares are estimated as 10% of production costs as $160 FY87M$. The total additional investment in the 21 airship system is then $270 FY87M$ bringing the total Program Acquisition Cost to:

a. $1591 FY87M$ for 2.5 (mcf) airships or 76 (M$) per airship

b. $1879 FY87M$ for 3.0 (mcf) airships or 90 (M$) per airship

c. $2262 FY87M$ for 3.5 (mcf) airships or 108 (M$) per airship

1. Airship Life Cycle Costs

The life cycle cost of the system is obtained by adding the operating and support costs to those of program acquisition. Annual operating and support costs were estimated from the Goodyear study as $6 FY87M$ [Ref. 36:p. 36]. Based on these figures, the life cycle cost of an airship system with 21 airships over 30 years would be approximately:

a. $5371 FY87M$ for 2.5 (mcf) airships

b. $5659 FY87M$ for 3.0 (mcf) airships

c. $6042 FY87M$ for 3.5 (mcf) airships

E. COST COMPARISON: AIRSHIPS VS. FIXED/ROTARY WING AIRCRAFT

As an alternative to the proposed airship program, a combination of fixed-wing and rotary-wing aircraft are considered in the same mission. The comparison will be based on providing 6 airborne fire control systems to the SAG. The fixed-wing aircraft will fill the surveillance and early warning role of the airship, while the rotary-wing aircraft will perform the fire control mission. The candidates for the surveillance platform are the land based E-

3A AWACS aircraft and the P-3 AWACS currently under development. The helicopters are modified from the current fleet ASW helicopter, the SH-60B (Lamps III).

Unit costs for these platforms, in millions of FY87$, are taken as:[5]

a. E-3A AWACS $110

b. P-3 AWACS $ 60

c. SH-60 $ 13

Keeping an aircraft continuously on station consumes a great deal of resources. As a rule of thumb, a minimum requirement would be to have 3 fixed-wing aircraft or 4 helicopters available to maintain such a continuous station. In the case here, the fixed-wing aircraft would be shuttling from their land base to the position of the surface action group. Considering the warning time available from the higher flying (compared to the proposed airship) fixed-wing aircraft, to be approximately 20 minutes, it could be feasible to keep the helicopters on deck on the escort vessels in a 5 minute standby status. Such a condition would provide for the least number of helicopters. For this comparison 8 helicopters is taken as an absolute minimum to maintain 6 helicopters in standby status.

Based on the above, and if modifying the fixed wing aircraft and helicopters could be accomplished for 3 M$ each, the cost, in FY87M$, of providing a 6 illuminator force to the SAG would be:

---

[5]The aircraft unit costs are from, for the E-3A, *U.S. Air Force Planning Factors* [Ref. 37:p. 124], for the SH-60B, *Military Cost Data Handbook* [Ref. 38:p. 124] and for the P-3 AEW the *Asian Defense Journal*, [Ref. 39:p. 23]. To cover the cost of current upgrades to the E-3A radar, $10 FY87M$ is added to the quoted unit cost. The cost of the modifications and additions, required to give the fixed-wing aircraft and helicopters the capability of the airborne fire control system proposed for the airship, is estimated as the cost of the fire control system (installed) of the 6 illuminator airship (page 92) divided by the number of fixed-wing aircraft and helicopters used. This estimate neglects the additional costs of the duplication of hardware and increased system complexity introduced when utilizing eleven aircraft vice one airship.

Airship System:		E-3A system:		P-3 system:	
1 airship @	$90	3 E-3As @	$110	3 P-3s @	$60
		8 SH-60s @	$13	8 SH-60s @	$13
		F/C system @	$33	F/C system @	$33
Total	$90		$467		$317

The acquisition cost of providing the 6 illuminator force to the SAG is on the order of 3.5 to 5 times lower using the airship. When allowing for a 100% underestimation of airship acquisition costs, the airship still provides the capability at one half of the cost of the alternatives considered.

1. Life Cycle Cost Comparison

The above estimates were made under the most favorable conditions to the land based surveillance aircraft. Figure 24 illustrates the relationship between the time a given aircraft can remain on station verses the distance of that station from the aircraft's base [Ref. 39:p. 23]. Once the SAG moves far enough away from the aircraft's base that a pipeline situation develops (multiple aircraft must be airborne in order to keep one station continuously filled), the cost of providing land based support rapidly escalates. Consider E-3As and P-3 AWACS operating 1500 nm from home base. Assuming block transit speeds of 500 and 400 knots respectively, the E-3A will average 2 aircraft airborne continuously and the P-3 will average 3. This implies, by rule of thumb, a 6 E-3A or a 9 P-3 aircraft force to support the SAG. When the SAG is 2000 nm from the aircraft's operating base (roughly the distance from Diego Garcia to the Straits of Hormuz), the P-3 would require 8 aircraft while the E-3A would require 6 aircraft. When the SAG exceeds from between 2200 to 2400 nautical miles from the aircraft base, support is no longer possible. The actual geographic distance from the SAG to the aircraft base is a poor indicator of the actual distance the aircraft may be required to transit. As demonstrated in the combined U.S. Air Force and Navy raid on Libya,

the distance land based aircraft fly to reach a particular destination is controlled by politics as well as geography.

When operating and support costs are considered the case for the proposed airship system becomes even stronger. Based on U.S. Air Force cost factors [Ref. 37], the annual cost of fielding one E-3A AWACS aircraft, in FY87$, is $11.02 million. This figure is based on operating the AWACS for an average of 125 hours a month. If the minimum 3 aircraft could support the 2 to 3 times greater flight hours required of the continuous (720 hours a month) station, the minimum cost would be greater than $33 million. The average cost of supporting one helicopter, taken from the same source, is $4.2 million (FY87$). The combined annual operating and support cost of the mixed fixed-wing and helicopter SAG support group would exceed $67 million FY87$. Over a 30 year life-cycle, if the airship annual operating cost is doubled to $12 million (FY87$), the comparative total costs of providing 6 illuminators to a SAG (in FY87M$) would be:

Airship based system:	$450
E-3A/SH-60 based system:	$2,477

It is not unreasonable to conclude that a SAG supported by 3 airships would be less costly than using a combination of fixed-wing aircraft and helicopters.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. In the convoy escort role, a first generation airship has the potential, at the level of capability examined, to maintain the combat effectiveness and thus extend the service life of current AAW platforms while concurrently reducing the number of hulls required by one half.

2. The threat to be opposed, in the employment of surface forces with and without tactical air support for a given level of threat resources, is fundamentally different and greater for the surface force without tactical aircover.

3. Given the capability of surface ships for mutual support, over the range of parameters examined high altitude high speed ASCMs are not a significant threat when seen in numbers less than the total force magazine capacity. The principal threat faced by unsupported surface forces is the potential for the opposition to exploit the surface ships' limited horizon, by use of low flying anti-ship cruise missiles. Long range, low flying ASCMs are relatively ineffective in isolating and concentrating force on individual units of the surface force (as opposed to discriminating against CV sized targets).

4. Of the low flying threats examined, the most stressful was posed by tactical aircraft (fighter/attack). Even with improved shipboard systems capable of reducing reaction time against ASCMs to as little 2 seconds and with SAMs with a Mach 3 average velocity at 3 nm from launch, a surface group is disadvantaged vis-a-vis tactical aircraft with Mach 2+, low flying ASCMs.

5. Over the range of threat and defensive parameters investigated, the potential for using surface ship forces in the "Revolution at Sea" concept will be limited when operating

independent of either land or carrier based tactical aircover or an airship and will further decline with logical near term improvements in sea skimming cruise missiles and tactical aircraft targeting.

6. Because of the potential long distance from land bases, fixed wing aircraft are inferior to airships for continuous support of a SAG.

7. Because of the large number of rotary wing aircraft required, the airship is preferable on nearly every basis for a fire control platform.

8. With development of the airship, (or the large variety and number of fixed and rotary wing assets required to substitute for the airships capability), the following conclusions may be drawn:

a. A four illuminator airship operating at or above 10,000 feet can be expected to reduce by 100% the number of low flying ASCMs , launched from tactical aircraft, penetrating to the inner defensive zone of a surface battle group merely by utilizing "off the shelf" technology. This conclusion is based on raid sizes up to 60 cruise missiles.

b. The base line airship performance level was established with the assumptions of;

i. an airship at an altitude of 10,000 feet

ii. an ECM clear environment(in terms of range of detection)

iii. dual SAM salvos utilizing a SAM with a kinetic range limit of on the order of 100 nautical miles

In terms of sensitivity, this performance level is maintainable as the operating altitude is reduced to 2,000 ft, and/or, the range of detection, the range to ECM burn-thru or the maximum range of the SAM, are reduced to on the order of 60 nm, if the number of airship illuminators is increased from 4 to 12 and single SAM salvos are used.

c. Beyond the "near term" threat, the most demanding response will be to a threat with simultaneous:

i. ASCM radar cross section reduction

ii. cruise altitude decrease

iii. terminal velocities increase

Response to such a threat is likely be the expensive both as to the electronics and the surface-to-air missiles required to cope, regardless of the platform employed. When considering the growth potential of the airship concept vis-a-vis the growth in threat capabilities, the airship airframe appears to be able to evolve at a rate commensurate with the threat. This is in terms of the economics of increasing airship displacement to support a payload capable of generating the RF power and or the aperture required against future threats.

d. Establishing the absolute level of survivability and vulnerability of the airship was not a primary issue of this study. However, cursory analysis demonstrates that the airship will be more survivable than any ship in a convoy or a battle group.

9. The first generation airship has the potential to make the AAW problem manageable for existing surface ships unaccompanied by land or sea based conventional airpower. With the airship capability added, the goals of the "Revolution at Sea" are attainable.

B. RECOMMENDATIONS

1. Based on the above conclusions, it would appear the cancellation of the Navy's Lighter-Than-Air research and development program was short sighted. The airship program should be reconstituted from the current DARPA R&D effort and funded at a level to regain, to the extent possible the original 1992 IOC.

2. To establish and maintain priorities, it is recommended the Navy's lighter-than-air program be sponsored, funded and controlled by the user community, Surface Warfare.

3. Development of the first generation airship should concentrate on "feasible" vice "optimal". With this in mind, it is recommended that as the best hedge against uncertainty, the airship purchased displace no less than 3.0 million cubic feet. A major purpose of early deployment is to gain tactical experience. Another purpose is to reduce uncertainty in airship production and operating costs.

4. Concurrent with the first generation airship development, research should begin to fill the requirements for a follow on, Aegis compatible, second generation airship.

5. Development should proceed with a "quick reaction" box launcher (SAM) for use on the first generation airship, based on NATO Sea Sparrow and CIWS technology. Such a development would offer a satisfactory solution to the "worst case" AAW threat to convoys and URGs from "in close" submarine launched ASCMs.

C. RECOMMENDATIONS FOR FURTHER STUDY

1. Investigate the feasibility and utility of the installation of airship-compatible SAMs in the ASW escorts scheduled to receive vertical launch modifications (DD-963s)

2. Explore the feasibility and impact of developing a long range (first CZ +) vertical launch "ASROC" to utilize the immediate, highly accurate, well classified datum the airship can provide against a OTH ASCM firing submarine.

3. Investigate using a heavy payload, low altitude variant of the basic first generation airship, adapted to the battle group ASW mission. In view of the quieting trends in submarines, the impact of such a platform employing large, high power, active sensors, such as multifrequency towed/dipped sonars and utilizing a heavy torpedo, with a high single shot probability of kill could be significant.

4. Investigate the tactical employment options provided by airships with regard to positioning of forces and scouting. The use of sophisticated high speed UAVs, launched and recovered from airships, controlled from surface ships may provide the battle group covert, real time, targeting quality data, at extended ranges.

5. Conduct additional study into the use of airships in a CV battle group environment.

APPENDIX A

FIRE CONTROL ALGORITHM AND SPREADSHEET IMPLEMENTATION

Based on the inputs for the altitude of the radar (airship or surface escort) and the incoming target, the spreadsheet determines the range at which the target will become engagable with the given SAM average velocity (point of earliest intercept). The program utilizes an algorithm which considers all of the additional factors which might delay launch of a SAM to make the earliest possible intercept. These factors are, the status of launchers (reload time), illuminator availability and the number of SAMs currently airborne. If any or all of these factors prevent making the earliest possible intercept, the algorithm determines when the longest lasting of the limiting conditions will be cleared. The time the last condition clears then becomes the time of launch. Based on the time of SAM launch, the time and position of the target's interception are recorded. The fire control algorithm, in its most generic form, is detailed below.

A. FIRE CONTROL ALGORITHM

Indexs:

target number = n, n = 1 to 60

dummy = j, j = all values < current i

launcher = l, as desired

illuminator = i, "" " "

Parameters:

RH,	input value for search radar height
TH,	input value for target height
TS,	input value for time interval between targets
DT,	input value for the fire control systems time to detect, establish a track and launch a missile against a target
ITR,	input value for length of terminal engagement phase
SAMV,	input value for SAM average velocity
ASCMV,	input value for target velocity
SAMSALVO,	number of SAMs launched in each salvo
MAXSAM,	maximum number of SAMs in flight
NUMSAM,	time indexed running total of the number of SAMs launched
NUMINT,	time indexed running total of the number of completed interception attempts
LOAD,	SAM launcher reload time
RXH,	range at which targets cross the radar horizon
OFT(n),	open fire time on the "n"th target, the time at which a SAM launch is possible
ROFT(n),	range of target at OFT(n)
LRT(n),	time the SAM launcher will be available for the "n"th target
LT(l,n)	launch time of salvo for target "n" from launcher "l"
LT(l,n-1),	launch time of last salvo from "l"th launcher
IFT(i,n-1),	time "i"th illuminator is available, earliest time "n"th target can enter terminal engagement phase

EPLT(n),	earliest possible launch time on "n" target
EPIT(n),	earliest possible intercept time for "n"th target
TOF(n),	time of flight from SAM launch to target n's interception
SIT(n),	scheduled interception time for target n
RANGE(n),	range to target n at intercept

STEP 1: {Initial target}

a. based on RH and TH determine RXH for run.

b. given RXH, DT and ASCMV determine ROFT(1) and set OFT(1) = 0

c. determine all interception parameters for n = 1

d. increment NUMSAM by SAMSALVO

STEP 2: {calculate time next target reaches open fire range}

a. n = n + 1 (if n is larger than the input size of the raid, stop)

b. OFT(n) = OFT(n-1) + TS

STEP 3: {calculate time next SAM salvo will be available}

a. LRT(n) = MIN [LT(l,n-1) + LOAD] for all l launchers

STEP 4: {calculate time the next illuminator will be available}

a. EPIT(n) = { MIN [IFT(i,n-1)] } + ITR

STEP 5: {given that an intercept would take place at EPIT(n), calculate the time at which the SALVO must have been launched, i.e. solve the equations of motion for SAM flight time given SAMV, ASCMV and the time of intercept (EPIT(n)}

a. EPLT(n) = [EPIT(n) - TOF(n)]

STEP 6: {determine the most limiting condition for firing on target}

a. LT(n) = MAX { OFT(n), LRT(n), EPLT(n) }

STEP 7: {determine if the maximum number of SAMs allowed in flight will be violated by a launch at time LT(n)}

a. IF { NUMSAM - NUMINT > MAXSAM } at LT(n) continue, o/w go to STEP 8

b. LT(n) ={ MIN [IT(n-j) , for all j], such that, IT(n-j)>LT(n)} (find the next scheduled interception after time LT(n))

STEP 8: {Using current LT(n), calculate and record all intercept parameters}

a. record TOF, RANGE schedule SIT(n)

b. increment NUMSAM by SAMSALVO

c. return to STEP 2

B. SPREADSHEET IMPLEMENTATION

In many respects the spreadsheet application greatly simplifies the fire control algorithm, albeit, at the loss of some generality. All of the indexing becomes an implict or explict function of postion on the spreadsheet. In typical fashion, a spreadsheet is divided by rows

and columns into "cells"[1]. The postion of a cell is defined by the column designation (usually a letter) and the number of the row in which it resides. As an example, Figure 25 shows a portion of typical output of the Framework III™ [Ref. 40] spreadsheet with the row/col designations.

CELLS

(A3) (B2)

	COLUMN			
ROW	A	B	C	D
1	INPUT DATA			
2	SAM SPEED, (NM/MIN)	30		
3	TARGET SPEED	10	NUMBER OF	
4	LAUNCHER CYCLE (SEC)	15	ATTACKING AIRCRAFT	
5	ILLUMINATION (SEC)	30	ASCM LAUNCH	
6	TARGET SPACING (SEC)	2	RANGE (NM)	
7				
8	SAM'S PER SALVO	2		
9	MAX SAM'S AIRBORNE	24		
10	SEARCH RADAR HEIGHT	10000	NUMBER OF ASCMs	
11	TARGET HEIGHT (FT)	25		
12	HORIZION RANGE (NM)	130.67	note; AIRSHIP (4 ILLUM)	
13	DETECTION DELAY (SEC)	30		
14	OPEN FIRE RANGE	125.67		
15				
16			LAUNCHER	ILLUMINATOR
17			READY	FREE
18	EARLYEST OPEN FIRE TIME:			
19	TARGET # 1	0	.00	.00
20	TARGET # 2	1	1.00	.00
22	TARGET # 4	3	16.00	.00
23	TARGET # 5	4	4.00	19.88
24	TARGET # 6	5	5.00	20.88

Figure 25. Partial Spreadsheet Output showing Cell Designations

[1]The procedures used here are based on the Framework III™ spreadsheet [Ref. 40]. However, spreadsheet conventions have become standardized in the implementation of most of the "full function" microcomputer based applications. The major differences are in the language used to define, and the allowed complexity of, cell formulas.

Information entered into a cell may take one of three forms, either character data (labels), numeric (constants), or formulas (short programs). In Figure 25, entries in column "A", A1 thru A14, are parameter names. Entries in column "B", B2 thru B14, are the values of the input parameters representing particular scenario assumptions. In terms of the fire control algorithm the cells in column "B" represent:

B2 = SAMV, SAM velocity in nautical miles per minute

B3 = ASCMV, target velocity in nautical miles per minute

B4 = LOAD, launcher cycle time in seconds (also used as the system effective inter-salvo time)

B5 = ITR, terminal illumination in seconds

B6 = TS, target spacing in seconds

B7, Blank

B8 = SAMSALVO, number of SAMs in a single salvo

B9 = MAXSAM, maximum number of SAMs which can be supported

B10 = RH, search radar height in feet

B11 = TH, target height in feet

B12 = RXH, range at which target crosses the search radar's horizon in nautical miles

B13 = DT, minimum time delay between target crossing horizon and SAM launch,in seconds

B14 = ROFT(1), range of target when it reachs the open fire position,in nautical miles

Rows 15 to 18 are blank. Starting with row 19, each row in the spreadsheet represent the action taken against a single target, in the order in which the targets cross the search radar horizon. Taking row 24 (6th target) as represenative, the cell entries are examined.

Cell A24 contains the label designating the row as containing data concerning the sixth target to reach open fire range.

Cell B24 contains the formula for calculating the time the 6th target reaches open fire range. The formula in B24 is expressed (in Framework II's syntax) as;

"B23 + $B$6"[2].

This means take the value found in cell B23, which is the time the 5th target reached open fire range, OFT(5), and add to it the value found in cell B6 (interval between targets, TS) and to display and use the value calculated as OFT(6).

Cell C24 contains the formula for determing when a SAM launcher will be available to support the engagement of the 6th target, LRT(6), and is expressed as;

"E22 + $B$4".

This means take the value found in cell E22 (the time of launch against target 4, LT(4), and add to it the effective launcher cycle time found in cell B4 (LOAD). Note that the above formula implies a two launcher system as the reference to the last launcher used refers to a position two rows above row 24. This follows from the assumption launchers are used sequencially. The number of launchers available in a given spreadsheet scenario depends on the offset between the current row number and the row referenced for the last time a launcher was used. In this case, if the formula in cell C24 had reffered to cell E23, a one launcher system would be implied, and if E20 had been referrenced a four launcher system would have been implied.

Cell D24 contains the formula determining when an illuminator will be available to start terminal tracking/illumination against the sixth target (IFT). The formula is "G20" which is a reference to the cell which contains the time illumination will cease on the second target.

---

[2]When a formula in a given cell is copied to another cell location, all cell addresses in the formula are modified to reflect the offset relative to the original location. In some instances it is desireable to prevent the normal relative address shift on some elements of a copied formula. The "$" symbol in front of the comumn or row in the cell name is used to "freeze" or prevent relative address shifts when the formula is copied to a new location.[Ref. 41: p. 142]

As with launchers, the number of illuminators is reflected in the difference between the current row and the row referenced. In this case, four illuminators are indicated.

Cell E24 contains the "subroutine" which determines the actual time of a SAM salvo against the sixth target, LT(6). The subroutine has three main functions;

a. determine the earliest possible time a SAM salvo could be launched against the sixth target given the launcher/illuminator status and the time the target crosses the firing horizon.

b. determine the number of SAM intercepts scheduled to occur by the most restrictive of either the illuminator or launcher constraints and the time of the next intercept scheduled after the clearing time of the controlling constraint.

c. determine the earliest launch time that will not violate the maximun allowable number of SAMs in flight and output the result as the salvo launch time.

A flow chart of "Launch Time Decision" is shown in Figure 26. The formula for cell E24 is in the program listing.

The spreadsheet uses nine additional columns (E to M) not shown in Figure 25. These additional columns are blank in Rows 1 to 18. From Row 19 down, columns F to M contain active cells which continue the single target calculations of columns B to E.

Cell F24 determines the time of flight (TOF(6)) from SAM launch to target intercept with the expression;

"((($B$14 - (($E24-$B24)/60)*$B$3))/($B$2+$B$3))*60".

This expression, in terms of the fire control algorithm, is;

"{[OFR - [((LT(6)-OFT(6))/60) ASCMV]] / (SAMV+ASCMV)} 60".

Cell G24 displays the scheduled "clock" time of the SAM salvo intercept with the expression;

"@PUT($M24,($E24 +$F24)),@RESULT(($E24+$F24))".

In terms of the fire control algorithm, this is;

"LT(6) + TOF(6)".

Cell Formula "E" (Row 24 shown)

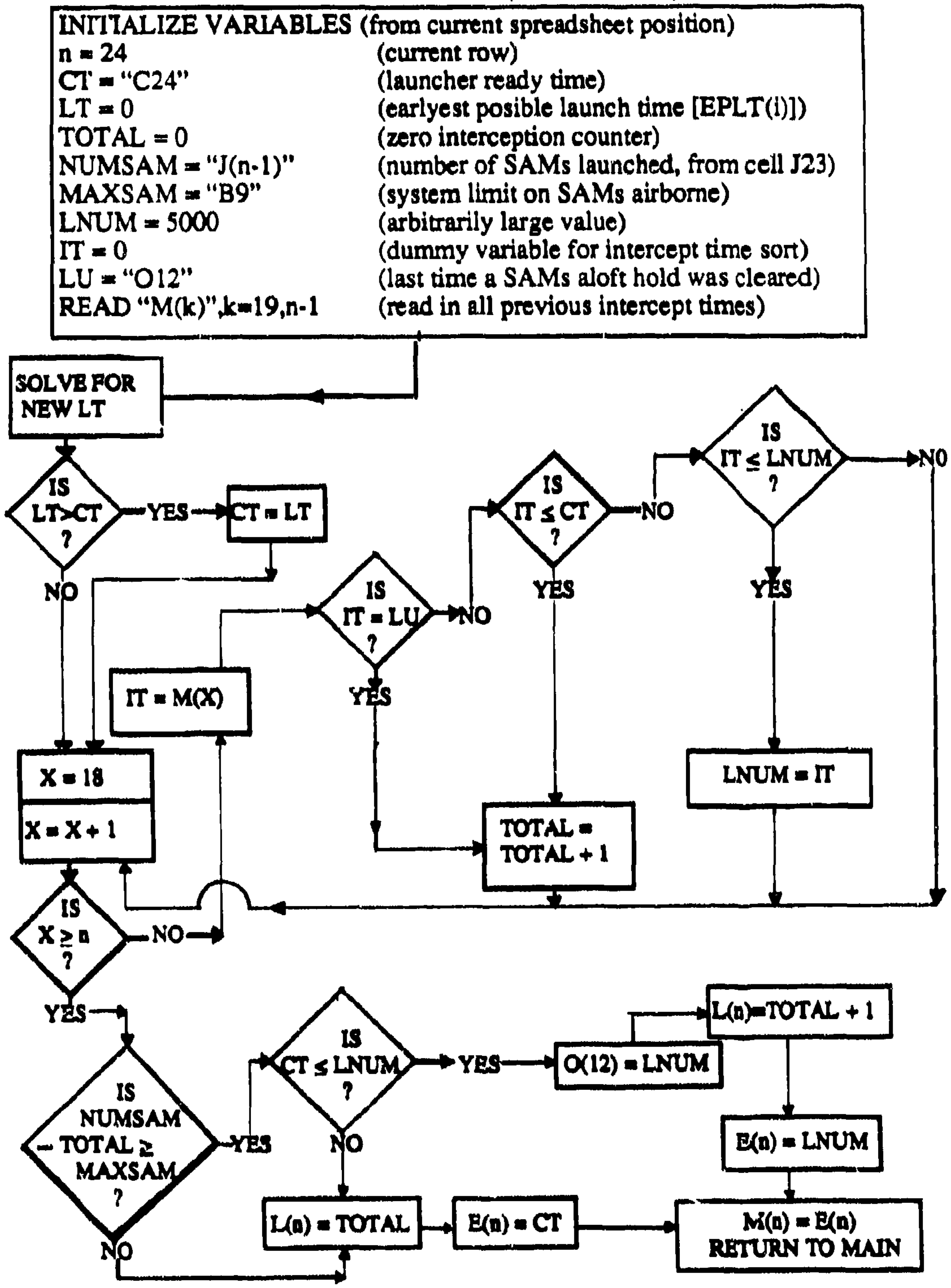

Figure 26. Flowchart of Launch Time Decision.

The expressions, "@PUT" and "@RESULT", are Framework II functions used to direct the result of the above calculation to the M24 cell location as well as the parent cell [Ref. 41:p. 501].

Cell H24 calculates the range of the target from the firing escort at the moment of SAM launch (LRANGE(6)) with the expression;

"$B$14 - ($E24 - $B24)* $B$3/60".

Cell I24 calculates the range of the target from the firing escort at the moment SAM intercept (RANGE(6)) with the expression;

"$H24 - (($F24/60) * ($B$3))".

Cell J24 is the sum of SAMs launched, NUMSAM, with the expression;

"J23+$B$8".

Cell K24 is the sum of the SAMs remaining in flight with the expression;

"J24 - L24".

In terms of the fire control algorithm this is;

"NUMSAM - NUMINT".

One additional column in the spreadsheet is used to perform initialization/housekeeping functions. Cells in column "O" are used here, but any group of blank cells may be utilized so long as they are above the target calculation rows, i.e. above row 19. The spreadsheet initialization formulas are shown at the top of the program listing (Appendix A, page xyz).

1. Spreadsheet Construction

By the methods indicated for the software package chosen, create a blank spreadsheet. Set the sheet's "Reclac" function to "row-wise". Starting with the blank spreadsheet, copy the labels and input parameter values from columns A and B into the same locations in the new rows 2 to 14. Copy the formulas from the listing for cells B12 and B14 into the same cells in the new spreadsheet. In column O, copy the initialization formulas into rows 2 to 11. Copy the formulas or thier equivalent, as shown for row 24 in the listing, into row 24 of the

new spreadsheet. Highlight the 24th row and select the spreadsheets "copy" function. Copy row 24 into the next 24 rows below and then into the 5 rows above. This gives the spreadsheet positions for 30 targets. If more targets are required, simply continue the copy process down the appropriate number of rows. The spreadsheet copying process automaticly changes formula row references based on the relative shift from the original row location. As Row 19 concerns data on the initial target, several cell locations in Row 19 will be in error. Erase the formulas in cells B19 and E19 and insert zeros. By definition, the time at which the first target reaches open fire range and the first SAM salvo is launched is scenario time zero. Erase the formulas in cells J19 and K19 and insert the expression "B8" (SAMs per Salvo).

Next, set the number of launcher and illuminators desired in the scenario. For illuminators, move to cell D19 (the illuminator free time for the first target) and access the spreadsheet's "Edit" function. Delete the formula residing in D19, replace it with a zero and exit the edit function. Now copy the new formula in D19 (a zero) down the "D" column to the depth such that zeros will appear in the same number of rows as illuminators are desired. Still in column "D", move to the first cell below the zero entries and enter the edit function. Enter the formula "G19" into the cell and exit the edit function. Highlight the newly edited cell and copy it to all cells below in column "D". The number of launchers in the scenario is handled in the same manner. The principle being to "hardwire" zeros in column "C" from row 19 to the row depth representing the desired number of launchers. Now, remaining in column "C", modify the formula in the next cell below to reference back to the launch time against the first target (E19). Copy the modified formula to all cells below the current position in column "C". The spreadsheet is now ready for use.

The expression "effective SAM inter-salvo time" has been used here for the fire control algorithm parameter "LOAD" which represents the actual time required to reload one launcher. The reason for this distinction is to take advantage of the spreadsheet's flexibility in portarying a system. As configured, the spreadsheet represents a surface escort with two

launchers, each launcher having two rails. Such an escort, with a 30 second launcher reload time, would be capable of firing a two SAM salvo every 15 seconds. It would be possible to model the same escort "system" in the spreadsheet by allowing for only one launcher if "LOAD" (cell B4) were set to 15 seconds. Conversely, two such twin launcher, dual rail escorts are modeled by establishing two launchers with an equivalent reload time of 15 seconds. To generate the large number of scenarios required in this study, the method, of leaving the number of launchers at two and varing the launcher reload time to meet the system equivalent, was found to save a great deal of time, as well as reducing the number of errors introduced by constantly editing the spreadsheet formulas. The method does have the disadvantage of making the scenario configeration, being modeled, unclear without close scurtiny of, or additional notation added to, the output.

2. Modeling Vertical Launcher Systems

A realistic model of multi-cell vertical launch escort can be made by setting up the spreadsheet to reflect one single rail launcher with a very short reload time. In the vertical launch case, the value contained in cell B4 does not represent launcher cycle time (or the fca value LOAD) but a time delay that the fire control system modeled must allow between SAM launches. To modify the spreadsheet as given, to a VLS configeration, enter "E19 + $B$4" as the formula for cell C20. Copy C20 to all cells in column "C" below row 20. Change the parameter (SAMs per SALVO) in cell B8 to one. If the further simplifing assumption is made that the fire control system modeled has no time delay between SAM launches (B4 is set to zero), then launcher considerations drop out as a controlling factor in the fire control algorithm. The assumption of no fire control delay between SAM launches was made in all scenario's involving "state of the art" escorts. To reflect no time delay restrictions between launches in the spreadsheet, enter "B2" as the formula for cell C19. Copy C19 to all cells, row 20 and below, in column "C". The result is a SAM will be available for a target at the time the target crosses the escort's horizon.

C. PROGRAM LISTING

The following is a partial listing (all columns, rows down to 24) of the code FRAMEWORK uses to create the fire control spreadsheet. The format of the listing is:

"cell address (column/row):

formula in cell"

Initialization formulas in column C lead off the listing followed by a row-wise listing of formulas for rows 2 to 24. Character fields (labels) are ignored in the listing. Numerical fields without formulas are shown with the last value entered.

```
B9:
  24

B10:
  10000
D10:
  60

B11:
  25

B12:
  (@SQRT(2*B10)+@SQRT(2*B11))*5280/6000

B13:
  30

B14:
  $B$12-(B13/60)*B3

B19:
  0
C19:
  0
D19:
  0
E19:
  0
F19:
  ($B$14/($B$2+$B$3))*60
G19:
  @PUT($M19,($E19 +$F19)),@RESULT(($E19+$F19))
H19:
  $B$14 - ($E19 - $B19)* $B$3/60
I19:
  $H19 - (($F19/60) * ($B$3))
J19:
  $B$8
```

```
K19:
  $B$8
L19:
  0

B20:
  B19+($B$6)
C20:
  B20 + 0
D20:
  0
E20:
  B20
F20:
  ((($B$14 - (($E20-$B20)/60)*$B$3))/($B$2+$B$3))*60
G20:
  @PUT($M20,($E20 +$F20)),@RESULT(($E20+$F20))
H20:
  $B$14 - ($E20 - $B20)* $B$3/60
I20:
  $H20 - (($F20/60) * ($B$3))
J20:
  (J19+$B$8)
K20:
  K19+$B$8
L20:
  0

B21:
  B20+($B$6)
C21:
  E19 + B$4
D21:
  0
E21:
  ;----LAUNCH TIME DECISION

@LOCAL(TOTAL,CT,LNUM,IT,LT),
 TOTAL:= 0,
 CT:= $C21,
 LNUM:= 5000,
 LT:= 0,
   LT:= ((($D21+$B$5)*($B$2+$B$3))-($B21*$B$3)-($B$14*60))/$B$2,
          @IF( LT > CT,
                 CT:= LT
          ),
  @WHILE(@GET($G$19:$G20)<>#NULL!,
    IT:= @GET($G$19:$G20),
          @IF( IT <> $O$12,
                  @IF( IT<=CT,
                        TOTAL:= TOTAL + $B$8,
                        @IF( IT<= LNUM,
                         LNUM:= IT
                        )
                  ),
          TOTAL:= TOTAL + $B$8
          ),
      @NEXT($G$19:$G20),
          ),
 @IF( (J20 - TOTAL) >= $B$9,
  @IF( CT < LNUM,
   @LIST( @PUT($O$12,LNUM),@PUT($L21,TOTAL+$B$8),@RESULT(LNUM)),
         @LIST( @PUT($L21,TOTAL),@RESULT(CT) )
  ),
   @LIST( @PUT($L21,TOTAL), @RESULT(CT))
```

```
)
        F21:
          ((($B$14 - (($E21-$B21)/60)*$B$3))/($B$2+$B$3))*60
        G21:
          @PUT($M21,($E21 +$F21)),@RESULT(($E21+$F21))
        H21:
          $B$14 - ($E21 - $B21)* $B$3/60
        I21:
          $H21 - (($F21/60) * ($B$3))
        J21:
          (J20+$B$8)
        K21:
          J21 - L21
        L21:
          0

        B22:
          B21+($B$6)
        C22:
          E20 + B$4
        D22:
          0
        E22:
          ;----LAUNCH TIME DECISION

          @LOCAL(TOTAL,CT,LNUM,IT,LT),
            TOTAL:= 0,
            CT:= $O22,
            LNUM:= 5000,
            LT:= 0,

LT:= ((($D22+$B$5)*($B$2+$B$3))-($B22*$B$3)-($B$14*60))/$B$2,

           @IF( LT > CT,
                    CT:= LT
     ),

@WHILE(@GET($G$19:$G21)<>#NULL!,
     IT:= @GET($G$19:$G21),
    @IF( IT <> $O$12,
              @IF( IT<=CT,
                      TOTAL:= TOTAL + $B$8,
                      @IF( IT<= LNUM,
                               LNUM:= IT
                        )
                ),

                            TOTAL:= TOTAL + $B$8
      ),

     @NEXT($G$19:$G21),
     ),

  @IF( (J21 - TOTAL) >= $B$9,
                     @IF( CT < LNUM,
   @LIST( @PUT($O$12,LNUM),@PUT($L22,TOTAL+$B$8),@RESULT(LNUM)),
       @LIST(@PUT($L22,TOTAL),@RESULT(CT))
                     ),
             @LIST(@PUT($L22,TOTAL), @RESULT(OT))
     )
        F22:
          ((($B$14 - (($E22-$B22)/60)*$B$3))/($B$2+$B$3))*60
        G22:
          @PUT($M22,($E22 +$F22)),@RESULT(($E22+$F22))
```

```
H22:
  $B$14 - ($E22 - $B22)* $B$3/60
I22:
  $H22 - (($F22/60) * ($B$3))
J22:
  (J21+$B$8)
K22:
  J22 - L22
L22:
  0

B23:
  B22+($B$3)
C23:
  E21 + B$4
D23:
  0
E23:
  ;-----LAUNCH TIME DECISION

  @LOCAL(TOTAL,CT,LNUM,IT,LT),
    TOTAL:= 0,
    CT:= $C23,
    LNUM:= 5000,
    LT:= 0,

LT:= ((($D23+$B$5)*($B$2+$B$3))-($B23*$B$3)-($B$14*60))/$B$2,
 @IF( LT > CT,
      CT:= LT
   ),

@WHILE(@GET($G$19:$G22)<>#NULL!,
   IT:= @GET($G$19:$G22),
  @IF( IT <> $O$12,
          @IF( IT<=CT,
                TOTAL:= TOTAL + $B$8,
                @IF( IT<= LNUM,
                       LNUM:= IT
                 )
          ),
                   TOTAL:= TOTAL + $B$8
   ),
   @NEXT($G$19:$G22),
  ),

@IF( (J22 - TOTAL) >= $B$9,
               @IF( CT < LNUM,
   @LIST( @PUT($O$12,LNUM),@PUT($L23,TOTAL+$B$8),@RESULT(LNUM)),
  @LIST(@PUT($N23:$O23,666),@PUT($L23,TOTAL),@RESULT(CT))
                ),
           @LIST( @PUT($L23,TOTAL), @RESULT(CT))
 )
    F23:
      ((($B$14 - (($E23-$B23)/60)*$B$3))/($B$2+$B$3))*60
    G23:
      @PUT($M23,($E23 +$F23)),@RESULT(($E23+$F23))
    H23:
      $B$14 - ($E23 - $B23)* $B$3/60
    I23:
      $H23 - (($F23/60) * ($B$3))
    J23:
      (J22+$B$8)
    K23:
      J23 - L23
```

```
L23:
  0

B24:
  B23+($B$6)
C24:
  E22 + B$4
D24:
  0
E24:
  ;——LAUNCH TIME DECISION

  @LOCAL(TOTAL,CT,LNUM,IT,LT),
     TOTAL:= 0,
     CT:= $C24,
     LNUM:= 5000,
     LT:= 0,

LT:= ((($D24+$B$5)*($B$2+$B$3))-($B24*$B$3)-($B$14*60))/$B$2,
  @IF( LT > CT,
        CT:= LT
   ),

@WHILE(@GET($G$19:$G23)<>#NULL!,
  IT:= @GET($G$19:$G23),
   @IF( IT <> $O$12,
          @IF( IT<=CT,
                 TOTAL:= TOTAL + $B$8,
                 @IF( IT<= LNUM,
                        LNUM:= IT
                   )
           ),
                    TOTAL:= TOTAL + $B$8
    ),

    @NEXT($G$19:$G23),
   ),

@IF( (J23 - TOTAL) >= $B$9,
              @IF( CT < LNUM,
  @LIST( @PUT($O$12,LNUM),@PUT($L24,TOTAL+$B$8),@RESULT(LNUM)),
        @LIST(@PUT($L24,TOTAL),@RESULT(CT))
               ),
          @LIST(@PUT($L24,TOTAL), @RESULT(CT))
 )
F24:
  ((($B$14 - (($E24-$B24)/60)*$B$3))/($B$2+$B$3))*60
G24:
  @PUT($M24,($E24 +$F24)),@RESULT(($E24+$F24))
H24:
  $B$14 - ($E24 - $B24)* $B$3/60
I24:
  $H24 - (($F24/60) * ($B$3))
J24:
  (J23+$B$8)
K24:
  J24 - L24
L24:
  0
```

D. Scenario Spreadsheet Output

The spreadsheet may be recreated by copying the listing as given into a blank spreadsheet, but the method (of copying and modifying row 24) described in the implementation section is likely to produce better results.

INPUT DATA			
SAM SPEED, (NM/MIN)	30		
TARGET SPEED	25		
LAUNCHER CYCLE TIME	.00	ATTACKING AIRCRAFT	30
ILLUMINATION (SEC.)	30		
TARGET SPACING (SEC.)	1	AACM LAUNCH RANGE	200
SAM'S PER SALVO	1	AACM SPEED	25
MAX SAM'S AIRBORNE	24		
SEARCH RADAR HEIGHT	75	NUMBER OF ASCM's	20
TARGET HEIGHT (FT.)	25000		
HORIZION RANGE (NM)	207.55	note: STATE OF THE ART AAW ESCORT, VERTICAL LAUNCH, PHASED ARRAY	
DETECTION DELAY (SEC)	40		
OPEN FIRE RANGE	190.89	DEFENDING AIRSHIP AT 10,000 FT. AIRSHIP IS WITHIN 25 NM.	

TIME TARGET AT OPEN FIRE RANGE:		LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE @ LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	208.24	208.24	190.89	104.12
TARGET # 2	1	.00	.00	.00	208.69	208.69	191.30	104.35
TARGET # 3	2	.00	.00	.00	209.15	209.15	191.72	104.57
TARGET # 4	3	.00	.00	.00	209.60	209.60	192.14	104.80
TARGET # 5	4	.00	208.24	51.67	186.57	238.24	171.02	93.29
TARGET # 6	5	.00	208.69	51.67	187.03	238.69	171.44	93.51
TARGET # 7	6	.00	209.15	51.67	187.48	239.15	171.86	93.74
TARGET # 8	7	.00	209.60	51.67	187.94	239.60	172.27	93.97
TARGET # 9	8	.00	238.24	103.33	164.90	268.24	151.16	82.45
TARGET # 10	9	.00	238.69	103.33	165.36	268.69	151.58	82.68
TARGET # 11	10	.00	239.15	103.33	165.81	269.15	152.00	82.91
TARGET # 12	11	.00	239.60	103.33	166.27	269.60	152.41	83.13
TARGET # 13	12	.00	268.24	155.00	143.24	298.24	131.30	71.62
TARGET # 14	13	.00	268.69	155.00	143.69	298.69	131.72	71.85
TARGET # 15	14	.00	269.15	155.00	144.15	299.15	132.14	72.07
TARGET # 16	15	.00	269.60	155.00	144.60	299.60	132.55	72.30
TARGET # 17	16	.00	298.24	206.67	121.57	328.24	111.44	60.79
TARGET # 18	17	.00	298.69	206.67	122.03	328.69	111.86	61.01
TARGET # 19	18	.00	299.15	206.67	122.48	329.15	112.27	61.24
TARGET # 20	19	.00	299.60	206.67	122.94	329.60	112.69	61.47
TARGET # 21	1	.00	328.24	274.17	84.07	358.24	77.07	42.04
TARGET # 22	2	.00	328.69	274.17	84.53	358.69	77.48	42.26
TARGET # 23	3	.00	329.15	274.17	84.98	359.15	77.90	42.49
TARGET # 24	4	.00	329.60	274.17	85.44	359.60	78.32	42.72
TARGET # 25	5	.00	358.24	325.83	62.40	388.24	57.20	31.20
TARGET # 26	6	.00	358.69	325.83	62.86	388.69	57.62	31.43
TARGET # 27	7	.00	359.15	325.83	63.31	389.15	58.04	31.66
TARGET # 28	8	.00	359.60	325.83	63.77	389.60	58.45	31.88
TARGET # 29	9	.00	388.24	377.50	40.74	418.24	37.34	20.37
TARGET # 30	10	.00	388.69	377.50	41.19	418.69	37.76	20.60
TARGET # 31	11	.00	389.15	377.50	41.65	419.15	38.18	20.82

INPUT DATA
SAM SPEED, (NM/MIN) 25
TARGET SPEED 10
LAUNCHER CYCLE TIME .00 ATTACKING AIRCRAFT 30
ILLUMINATION (SEC.) 8
TARGET SPACING (SEC.) 1 ASCM LAUNCH RANGE 30

SAM'S PER SALVO 1 ASCM SPEED 20
MAX SAM'S AIRBORNE 24
SEARCH RADAR HEIGHT 75 NUMBER OF ASCM's 60
TARGET HEIGHT (FT.) 6
HORIZION RANGE (NM) 13.83 note: STATE OF THE ART AAW ESCORT, VERTICAL LAUNCH, PHASED ARRAY
DETECTION DELAY (SEC) 15
OPEN FIRE RANGE 11.33

TIME TARGET AT OPEN	FIRE RANGE:	LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE @ LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	19.42	19.42	11.33	8.09
TARGET # 2	1	.00	.00	.00	19.70	19.70	11.49	8.21
TARGET # 3	2	.00	.00	.00	19.99	19.99	11.66	8.33
TARGET # 4	3	.00	.00	.00	20.27	20.27	11.83	8.45
TARGET # 5	4	.00	19.42	9.60	17.82	27.42	10.39	7.42
TARGET # 6	5	.00	19.70	9.60	18.10	27.70	10.56	7.54
TARGET # 7	6	.00	19.99	9.60	18.39	27.99	10.73	7.66
TARGET # 8	7	.00	20.27	9.60	18.67	28.27	10.89	7.78
TARGET # 9	8	.00	27.42	19.20	16.22	35.42	9.46	6.76
TARGET # 10	9	.00	27.70	19.20	16.50	35.70	9.63	6.88
TARGET # 11	10	.00	27.99	19.20	16.79	35.99	9.79	6.99
TARGET # 12	11	.00	28.27	19.20	17.07	36.27	9.96	7.11
TARGET # 13	12	.00	35.42	28.80	14.62	43.42	8.53	6.09
TARGET # 14	13	.00	35.70	28.80	14.90	43.70	8.69	6.21
TARGET # 15	14	.00	35.99	28.80	15.19	43.99	8.86	6.33
TARGET # 16	15	.00	36.27	28.80	15.47	44.27	9.03	6.45
TARGET # 17	16	.00	43.42	38.40	13.02	51.42	7.59	5.42
TARGET # 18	17	.00	43.70	38.40	13.30	51.70	7.76	5.54
TARGET # 19	18	.00	43.99	38.40	13.59	51.99	7.93	5.66
TARGET # 20	19	.00	44.27	38.40	13.87	52.27	8.09	5.78
TARGET # 21	20	.00	51.42	48.00	11.42	59.42	6.66	4.76
TARGET # 22	21	.00	51.70	48.00	11.70	59.70	6.83	4.88
TARGET # 23	22	.00	51.99	48.00	11.99	59.99	6.99	4.99
TARGET # 24	23	.00	52.27	48.00	12.27	60.27	7.16	5.11
TARGET # 25	24	.00	59.42	57.60	9.82	67.42	5.73	4.09
TARGET # 26	25	.00	59.70	57.60	10.10	67.70	5.89	4.21
TARGET # 27	26	.00	59.99	57.60	10.39	67.99	6.06	4.33
TARGET # 28	27	.00	60.27	57.60	10.67	68.27	6.23	4.45
TARGET # 29	28	.00	67.42	67.20	8.22	75.42	4.79	3.42
TARGET # 30	29	.00	67.70	67.20	8.50	75.70	4.96	3.54
TARGET # 31	30	.00	67.99	67.20	8.79	75.99	5.13	3.66

INPUT DATA
SAM SPEED, (NM/MIN) 25
TARGET SPEED 15
LAUNCHER CYCLE TIME .00 ATTACKING AIRCRAFT 30
ILLUMINATION (SEC.) 8
TARGET SPACING (SEC.) 1 ASCM LAUNCH RANGE 30

SAM'S PER SALVO 1 ASCM SPEED 20
MAX SAM'S AIRBORNE 24
SEARCH RADAR HEIGHT 75 NUMBER OF ASCM's 60
TARGET HEIGHT (FT.) 6
HORIZION RANGE (NM) 13.83 note: STATE OF THE ART AAW ESCORT, VERTICAL LAUNCH, PHASED ARRAY
DETECTION DELAY (SEC) 15
OPEN FIRE RANGE 10.08

TIME TARGET AT OPEN	FIRE RANGE:	LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE @ LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	15.11	15.11	10.08	6.30
TARGET # 2	1	.00	.00	.00	15.49	15.49	10.33	6.45

TARGET # 3	2	.00	.00	.00	15.86	15.86	10.58	6.61
TARGET # 4	3	.00	.00	.00	16.24	16.24	10.83	6.77
TARGET # 5	4	.00	15.11	10.40	12.71	23.11	8.48	5.30
TARGET # 6	5	.00	15.49	10.40	13.09	23.49	8.73	5.45
TARGET # 7	6	.00	15.86	10.40	13.46	23.86	8.98	5.61
TARGET # 8	7	.00	16.24	10.40	13.84	24.24	9.23	5.77
TARGET # 9	8	.00	23.11	20.80	10.31	31.11	6.88	4.30
TARGET # 10	9	.00	23.49	20.80	10.69	31.49	7.13	4.45
TARGET # 11	10	.00	23.86	20.80	11.06	31.86	7.38	4.61
TARGET # 12	11	.00	24.24	20.80	11.44	32.24	7.63	4.77
TARGET # 13	12	.00	31.11	31.20	7.91	39.11	5.28	3.30
TARGET # 14	13	.00	31.49	31.20	8.29	39.49	5.53	3.45
TARGET # 15	14	.00	31.86	31.20	8.66	39.86	5.78	3.61
TARGET # 16	15	.00	32.24	31.20	9.04	40.24	6.03	3.77
TARGET # 17	16	.00	39.11	41.60	5.51	47.11	3.68	2.30
TARGET # 18	17	.00	39.49	41.60	5.89	47.49	3.93	2.45
TARGET # 19	18	.00	39.86	41.60	6.26	47.86	4.18	2.61
TARGET # 20	19	.00	40.24	41.60	6.64	48.24	4.43	2.77
TARGET # 21	20	.00	47.11	52.00	3.11	55.11	2.08	1.30
TARGET # 22	21	.00	47.49	52.00	3.49	55.49	2.33	1.45
TARGET # 23	22	.00	47.86	52.00	3.86	55.86	2.58	1.61
TARGET # 24	23	.00	48.24	52.00	4.24	56.24	2.83	1.77
TARGET # 25	24	.00	55.11	62.40	.71	63.11	.48	.30
TARGET # 26	25	.00	55.49	62.40	1.09	63.49	.73	.45
TARGET # 27	26	.00	55.86	62.40	1.46	63.86	.98	.61
TARGET # 28	27	.00	56.24	62.40	1.84	64.24	1.23	.77
TARGET # 29	28	.00	63.11	72.80	-1.69	71.11	-1.12	-.70
TARGET # 30	29	.00	53.49	72.80	-1.31	71.49	-.87	-.55
TARGET # 31	30	.00	63.86	72.80	-.94	71.86	-.6[illegible]	-.39

INPUT DATA

SAM SPEED, (NM/MIN)	25		
TARGET SPEED	20		
LAUNCHER CYCLE TIME	.00	ATTACKING AIRCRAFT	30
ILLUMINATION (SEC.)	8		
TARGET SPACING (SEC.)	1	ASCM LAUNCH RANGE	30
SAM'S PER SALVO	1	ASCM SPEED	20
MAX SAM'S AIRBORNE	24		
SEARCH RADAR HEIGHT	75	NUMBER OF ASCM's	60
TARGET HEIGHT (FT.)	25		
HORIZION RANGE (NM)	17.00	note: STATE OF THE ART AAW ESCORT, VERTICAL LAUNCH, PHASED ARRAY	
DETECTION DELAY (SEC)	20		
OPEN FIRE RANGE	10.33		

TIME TARGET AT OPEN	FIRE RANGE:	LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE @ LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	13.78	13.78	10.33	5.74
TARGET # 2	1	.00	.00	.00	14.22	14.22	10.67	5.93
TARGET # 3	2	.00	.00	.00	14.67	14.67	11.00	6.11
TARGET # 4	3	.00	.00	.00	15.11	15.11	11.33	6.30
TARGET # 5	4	.00	13.78	11.20	10.58	21.78	7.93	4.41
TARGET # 6	5	.00	14.22	11.20	11.02	22.22	8.27	4.59
TARGET # 7	6	.00	14.67	11.20	11.47	22.67	8.60	4.78
TARGET # 8	7	.00	15.11	11.20	11.91	23.11	8.93	4.96
TARGET # 9	8	.00	21.78	22.40	7.38	29.78	5.53	3.07
TARGET # 10	9	.00	22.22	22.40	7.82	30.22	5.87	3.26
TARGET # 11	10	.00	22.67	22.40	8.27	30.67	6.20	3.44
TARGET # 12	11	.00	23.11	22.40	8.71	31.11	6.53	3.63
TARGET # 13	12	.00	29.78	33.60	4.18	37.78	3.13	1.74
TARGET # 14	13	.00	30.22	33.60	4.62	38.22	3.47	1.93
TARGET # 15	14	.00	30.67	33.60	5.07	38.67	3.80	2.11
TARGET # 16	15	.00	31.11	33.60	5.51	39.11	4.13	2.30
TARGET # 17	16	.00	37.78	44.80	.98	45.78	.73	.41
TARGET # 18	17	.00	38.22	44.80	1.42	46.22	1.07	.59
TARGET # 19	18	.00	38.67	44.80	1.87	46.67	1.40	.78
TARGET # 20	19	.00	39.11	44.80	2.31	47.11	1.73	.96
TARGET # 21	20	.00	45.78	56.00	-2.22	53.78	-1.67	-.93
TARGET # 22	21	.00	46.22	56.00	-1.78	54.22	-1.33	-.74
TARGET # 23	22	.00	46.67	56.00	-1.33	54.67	-1.00	-.56

TARGET # 24	23	.00	47.11	56.00	-.89	55.11	-.67	-.37
TARGET # 25	24	.00	53.78	67.20	-5.42	61.78	-4.07	-2.26
TARGET # 26	25	.00	54.22	67.20	-4.98	62.22	-3.73	-2.07
TARGET # 27	26	.00	54.67	67.20	-4.53	62.67	-3.40	-1.89
TARGET # 28	27	.00	55.11	67.20	-4.09	63.11	-3.07	-1.70
TARGET # 29	28	.00	61.78	78.40	-8.62	69.78	-6.47	-3.59
TARGET # 30	29	.00	62.22	78.40	-8.18	70.22	-6.13	-3.41
TARGET # 31	30	.00	62.67	78.40	-7.73	70.67	-5.80	-3.22

INPUT DATA

SAM SPEED, (NM/MIN)	30		
TARGET SPEED	10		
LAUNCHER CYCLE TIME	30	ATTACKING AIRCRAFT	30
ILLUMINATION (SEC.)	30		
TARGET SPACING (SEC.)	2	ASCM LAUNCH RANGE	30
SAM'S PER SALVO	2	ASCM SPEED	20
MAX SAM'S AIRBORNE	12		
SEARCH RADAR HEIGHT	10000	NUMBER OF ASCM's	60
TARGET HEIGHT (FT.)	25		
HORIZION RANGE (NM)	130.67	note: AIRSHIP (2 ILLUM.), LINKED WITH 1 NTU ESCORT (CG-16)	
DETECTION DELAY (SEC)	80		
OPEN FIRE RANGE	117.34		

	TIME TARGET AT OPEN FIRE RANGE:	LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE @ LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	176.01	176.01	117.34	88.00
TARGET # 2	2	2.00	.00	2.00	176.01	178.01	117.34	88.00
TARGET # 3	4	30.00	176.01	38.67	167.34	206.01	111.56	83.67
TARGET # 4	6	32.00	178.01	40.67	167.34	208.01	111.56	83.67
TARGET # 5	8	68.67	206.01	77.33	158.68	236.01	105.78	79.34
TARGET # 6	10	70.67	208.01	79.33	158.68	238.01	105.78	79.34
TARGET # 7	12	107.33	236.01	176.01	135.01	311.02	90.00	67.50
TARGET # 8	14	109.33	238.01	178.01	135.01	313.02	90.00	67.50
TARGET # 9	16	206.01	311.02	214.68	126.34	341.02	84.23	63.17
TARGET # 10	18	208.01	313.02	216.68	126.34	343.02	84.23	63.17
TARGET # 11	20	244.68	341.02	253.34	117.67	371.02	78.45	58.84
TARGET # 12	22	246.68	343.02	255.34	117.67	373.02	78.45	58.84
TARGET # 13	24	283.34	371.02	311.02	104.26	415.27	69.50	52.13
TARGET # 14	26	285.34	373.02	313.02	104.26	417.27	69.50	52.13
TARGET # 15	28	341.02	415.27	349.68	95.59	445.27	63.73	47.79
TARGET # 16	30	343.02	417.27	351.68	95.59	447.27	63.73	47.79
TARGET # 17	32	379.68	445.27	388.35	86.92	475.27	57.95	43.46
TARGET # 18	34	381.68	447.27	390.35	86.92	477.27	57.95	43.46
TARGET # 19	36	418.35	475.27	427.02	78.26	505.27	52.17	39.13
TARGET # 20	38	420.35	477.27	429.02	78.26	507.27	52.17	39.13
TARGET # 21	40	457.02	505.27	465.68	69.59	535.27	46.39	34.79
TARGET # 22	42	459.02	507.27	467.68	69.59	537.27	46.39	34.79
TARGET # 23	44	495.68	535.27	504.35	60.92	565.27	40.61	30.46
TARGET # 24	46	497.68	537.27	506.35	60.92	567.27	40.61	30.46
TARGET # 25	48	534.35	565.27	543.02	52.26	595.27	34.84	26.13
TARGET # 26	50	536.35	567.27	545.02	52.26	597.27	34.84	26.13
TARGET # 27	52	573.02	595.27	581.68	43.59	625.27	29.06	21.79
TARGET # 28	54	575.02	597.27	583.68	43.59	627.27	29.06	21.79
TARGET # 29	56	611.68	625.27	620.35	34.92	655.27	23.28	17.46
TARGET # 30	58	613.68	627.27	622.35	34.92	657.27	23.28	17.46
TARGET # 31	60	650.35	655.27	659.02	26.26	685.27	17.50	13.13

INPUT DATA

SAM SPEED, (NM/MIN)	30		
TARGET SPEED	10		
LAUNCHER CYCLE TIME	15.00	ATTACKING AIRCRAFT	30
ILLUMINATION (SEC.)	30		
TARGET SPACING (SEC.)	1	ASCM LAUNCH RANGE	130
SAM'S PER SALVO	2	ASCM SPEED	10
MAX SAM'S AIRBORNE	24		
SEARCH RADAR HEIGHT	10000	NUMBER OF ASCM'S	60
TARGET HEIGHT (FT.)	25		
HORIZION RANGE (NM)	130.67	note: 4 ILLUMINATOR AIRSHIP, 2 NTU AAW ESCORTS	
DETECTION DELAY (SEC)	80		
OPEN FIRE RANGE	117.34		

TIME TARGET AT OPEN FIRE RANGE:		LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE @ LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	176.01	176.01	117.34	88.00
TARGET # 2	1	2.00	.00	2.00	175.76	177.76	117.17	87.88
TARGET # 3	2	15.00	.00	15.00	172.76	187.76	115.17	86.38
TARGET # 4	3	17.00	.00	17.00	172.51	189.51	115.01	86.25
TARGET # 5	4	30.00	176.01	38.67	167.34	206.01	111.56	83.67
TARGET # 6	5	32.00	177.76	40.67	167.09	207.76	111.40	83.55
TARGET # 7	6	53.67	187.76	53.67	164.09	217.76	109.40	82.05
TARGET # 8	7	55.67	189.51	55.67	163.84	219.51	109.23	81.92
TARGET # 9	8	68.67	206.01	77.33	158.68	236.01	105.78	79.34
TARGET # 10	9	70.67	207.76	79.33	158.43	237.76	105.62	79.21
TARGET # 11	10	92.33	217.76	92.33	55.43	247.76	103.62	77.71
TARGET # 12	11	94.33	219.51	94.33	155.18	249.51	103.45	77.59
TARGET # 13	12	107.33	236.01	176.01	135.01	311.02	90.00	67.50
TARGET # 14	13	109.33	237.76	177.76	134.82	312.58	89.88	67.41
TARGET # 15	14	191.01	247.76	191.01	131.76	322.77	87.84	65.88
TARGET # 16	15	192.76	249.51	192.76	131.57	324.33	87.71	65.78
TARGET # 17	16	206.01	311.02	214.68	126.34	341.02	84.23	63.17
TARGET # 18	17	207.76	312.58	216.43	126.15	342.58	84.10	63.08
TARGET # 19	18	229.68	322.77	229.68	123.09	352.77	82.06	61.55
TARGET # 20	19	231.43	324.33	231.43	122.90	354.33	81.94	61.45
TARGET # 21	20	244.68	341.02	253.34	117.67	371.02	78.45	58.84
TARGET # 22	21	246.43	342.58	255.09	117.49	372.58	78.32	58.74
TARGET # 23	22	268.34	352.77	268.34	114.42	382.77	76.28	57.21
TARGET # 24	23	270.09	354.33	270.09	114.24	384.33	76.16	57.12
TARGET # 25	24	283.34	371.02	311.02	104.26	415.27	69.50	52.13
TARGET # 26	25	285.09	372.58	312.58	104.11	416.69	69.41	52.06
TARGET # 27	26	326.02	382.77	326.02	101.01	427.02	67.34	50.50
TARGET # 28	27	327.58	384.33	327.50	100.86	428.44	67.24	50.43
TARGET # 29	28	341.02	415.27	349.68	95.59	445.27	63.73	47.79
TARGET # 30	29	342.58	416.69	351.25	95.45	446.69	63.63	47.72
TARGET # 31	30	364.68	427.02	364.68	92.34	457.02	61.56	46.17
TARGET # 32	31	366.25	428.44	366.25	92.20	458.44	61.47	46.10
TARGET # 33	32	379.68	445.27	388.35	86.92	475.27	57.95	43.46
TARGET # 34	33	381.25	446.69	389.91	86.78	476.69	57.85	43.39
TARGET # 35	34	403.35	457.02	403.35	83.67	487.02	55.78	41.84
TARGET # 36	35	404.91	458.44	404.91	83.53	488.44	55.69	41.77
TARGET # 37	36	418.35	475.27	427.02	78.26	505.27	52.17	39.13
TARGET # 38	37	419.91	476.69	428.50	78.11	506.69	52.08	39.06
TARGET # 39	38	442.02	487.02	442.02	75.01	517.02	50.00	37.50
TARGET # 40	39	443.58	488.44	443.58	74.86	518.44	49.91	37.43
TARGET # 41	40	457.02	505.27	465.68	69.59	535.27	46.39	34.79
TARGET # 42	41	458.58	506.69	467.25	69.45	536.69	46.30	34.72
TARGET # 43	42	480.68	517.02	480.68	66.34	547.02	44.23	33.17
TARGET # 44	43	482.25	518.44	482.25	66.20	548.44	44.13	33.10
TARGET # 45	44	495.68	535.27	504.35	60.92	565.27	40.61	30.46
TARGET # 46	45	497.25	536.69	505.91	60.78	566.69	40.52	30.39
TARGET # 47	46	519.35	547.02	519.35	57.67	577.02	38.45	28.84
TARGET # 48	47	520.91	548.44	520.91	57.53	578.44	38.35	28.77
TARGET # 49	48	534.35	565.27	543.02	52.26	595.27	34.84	26.13
TARGET # 50	49	535.91	566.69	544.58	52.11	596.69	34.74	26.06
TARGET # 51	50	558.02	577.02	558.02	49.01	607.02	32.67	24.50
TARGET # 52	51	559.58	578.44	559.58	48.86	608.44	32.58	24.43
TARGET # 53	52	573.02	595.27	581.68	43.59	625.27	29.06	21.79
TARGET # 54	53	574.58	596.69	583.25	43.45	626.69	28.97	21.72

TARGET # 55	54	596.68	607.02	596.68	40.34	637.02	26.89	20.17
TARGET # 56	55	598.25	608.44	598.25	40.20	638.44	26.80	20.10
TARGET # 57	56	611.68	625.27	620.35	34.92	655.27	23.28	17.46
TARGET # 58	57	613.25	626.69	621.91	34.78	656.69	23.19	17.39
TARGET # 59	58	635.35	637.02	635.35	31.67	667.02	21.11	15.84
TARGET # 60	59	636.91	638.44	636.91	31.53	668.44	21.02	15.77
TARGET # 61	60	650.35	655.27	659.02	26.26	685.27	17.50	13.13

INPUT DATA

SAM SPEED, (NM/MIN)	30		
TARGET SPEED	10		
LAUNCHER CYCLE TIME	15.00	ATTACKING AIRCRAFT	30
ILLUMINATION (SEC.)	30		
TARGET SPACING (SEC.)	2	ASCM LAUNCH RANGE	30
SAM'S PER SALVO	2	ASCM SPEED	10
MAX SAM'S AIRBORNE	24		
SEARCH RADAR HEIGHT	10000	NUMBER OF ASCM's	60
TARGET HEIGHT (FT.)	25		
HORIZION RANGE (NM)	130.67	note: 4 ILLUMINATOR AIRSHIP, 2 NTU AAW ESCORTS	
DETECTION DELAY (SEC)	80		
OPEN FIRE RANGE	117.34		

TIME TARGET AT OPEN	FIRE RANGE:	LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE @ LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	176.01	176.01	117.34	88.00
TARGET # 2	2	2.00	.00	2.00	176.01	178.01	117.34	88.00
TARGET # 3	4	15.00	.00	15.00	173.26	188.26	115.51	86.63
TARGET # 4	6	17.00	.00	17.00	173.26	190.26	115.51	86.63
TARGET # 5	8	30.00	176.01	37.33	168.68	206.01	112.45	84.34
TARGET # 6	10	32.00	178.01	39.33	168.68	208.01	112.45	84.34
TARGET # 7	12	52.33	188.26	52.33	165.93	218.26	110.62	82.96
TARGET # 8	14	54.33	190.26	54.33	165.93	220.26	110.62	82.96
TARGET # 9	16	67.33	206.01	74.67	161.34	236.01	107.56	80.67
TARGET # 10	18	69.33	208.01	76.67	161.34	238.01	107.56	80.67
TARGET # 11	20	89.67	218.26	89.67	158.59	248.26	105.73	79.30
TARGET # 12	22	91.67	220.26	91.67	158.59	250.26	105.73	79.30
TARGET # 13	24	104.67	236.01	176.01	138.01	314.02	92.00	69.00
TARGET # 14	26	106.67	238.01	178.01	138.01	316.02	92.00	69.00
TARGET # 15	28	191.01	248.26	191.01	135.26	326.27	90.17	67.63
TARGET # 16	30	193.01	250.26	193.01	135.26	328.27	90.17	67.63
TARGET # 17	32	206.01	314.02	213.34	130.67	344.02	87.12	65.34
TARGET # 18	34	208.01	316.02	215.34	130.67	346.02	87.12	65.34
TARGET # 19	36	228.34	326.27	228.34	127.92	356.27	85.28	63.96
TARGET # 20	38	230.34	328.27	230.34	127.92	358.27	85.28	63.96
TARGET # 21	40	243.34	344.02	250.68	123.34	374.02	82.23	61.67
TARGET # 22	42	245.34	346.02	252.68	123.34	376.02	82.23	61.67
TARGET # 23	44	265.68	356.27	265.68	120.59	386.27	80.39	60.30
TARGET # 24	46	267.68	358.27	267.68	120.59	388.27	80.39	60.30
TARGET # 25	48	280.68	374.02	314.02	109.51	423.52	73.00	54.75
TARGET # 26	50	282.68	376.02	316.02	109.51	425.52	73.00	54.75
TARGET # 27	52	329.02	386.27	329.02	106.76	435.77	71.17	53.38
TARGET # 28	54	331.02	388.27	331.02	106.76	437.77	71.17	53.38
TARGET # 29	56	344.02	423.52	351.35	102.17	453.52	68.11	51.09
TARGET # 30	58	346.02	425.52	353.35	102.17	455.52	68.11	51.09
TARGET # 31	0	366.35	435.77	386.35	79.42	465.77	52.95	39.71
TARGET # 32	2	368.35	437.77	388.35	79.42	467.77	52.95	39.71
TARGET # 33	4	401.35	453.52	408.68	74.84	483.52	49.89	37.42
TARGET # 34	6	403.35	455.52	410.68	74.84	485.52	49.89	37.42
TARGET # 35	8	423.68	465.77	423.68	72.09	495.77	48.06	36.04
TARGET # 36	10	425.68	467.77	425.68	72.09	497.77	48.06	36.04
TARGET # 37	12	438.68	483.52	446.02	67.51	513.52	45.00	33.75
TARGET # 38	14	440.68	485.52	448.02	67.51	515.52	45.00	33.75
TARGET # 39	16	461.02	495.77	461.02	64.76	525.77	43.17	32.38
TARGET # 40	18	463.02	497.77	463.02	64.76	527.77	43.17	32.38
TARGET # 41	20	476.02	513.52	483.35	60.17	543.52	40.11	30.09
TARGET # 42	22	478.02	515.52	485.35	60.17	545.52	40.11	30.09
TARGET # 43	24	498.35	525.77	498.35	57.42	555.77	38.28	28.71
TARGET # 44	26	500.35	527.77	500.35	57.42	557.77	38.28	28.71
TARGET # 45	28	513.35	543.52	520.68	52.84	573.52	35.23	26.42

TARGET # 46	30	515.35	545.52	522.68	52.84	575.52	35.23	26.42
TARGET # 47	32	535.68	555.77	535.68	50.09	585.77	33.39	25.04
TARGET # 48	34	537.68	557.77	537.68	50.09	587.77	33.39	25.04
TARGET # 49	36	550.68	573.52	558.02	45.51	603.52	30.34	22.75
TARGET # 50	38	552.68	575.52	560.02	45.51	605.52	30.34	22.75
TARGET # 51	40	573.02	585.77	573.02	42.76	615.77	28.50	21.38
TARGET # 52	42	575.02	587.77	575.02	42.76	617.77	28.50	21.38
TARGET # 53	44	588.02	603.52	595.35	38.17	633.52	25.45	19.09
TARGET # 54	46	590.02	605.52	597.35	38.17	635.52	25.45	19.09
TARGET # 55	48	610.35	615.77	610.35	35.42	645.77	23.61	17.71
TARGET # 56	50	612.35	617.77	612.35	35.42	647.77	23.61	17.71
TARGET # 57	52	625.35	633.52	632.68	30.84	663.52	20.56	15.42
TARGET # 58	54	627.35	635.52	634.68	30.84	665.52	20.56	15.42
TARGET # 59	56	647.68	645.77	647.68	28.09	675.77	18.73	14.04
TARGET # 60	58	649.68	647.77	649.68	28.09	677.77	10.73	14.04
TARGET # 61	60	662.68	663.52	670.02	23.51	693.52	15.67	11.75

INPUT DATA

SAM SPEED, (NM/MIN)	30		
TARGET SPEED	10		
LAUNCHER CYCLE TIME	15.00	ATTACKING AIRCRAFT	30
ILLUMINATION (SEC.)	30		
TARGET SPACING (SEC.)	2	ASCM LAUNCH RANGE	30
SAM'S PER SALVO	2	ASCM SPEED	20
MAX SAM'S AIRBORNE	24		
SEARCH RADAR HEIGHT	10000	NUMBER OF ASCM's	60
TARGET HEIGHT (FT.)	25		
HORIZION RANGE (NM)	130.67	note: AIRSHIP (6 ILLUM.), LINKED WITH 2 NTU ESCORTS (CG-16)	
DETECTION DELAY (SEC)	80		
OPEN FIRE RANGE	117.34		

TIME TARGET AT OPEN FIRE RANGE:		LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	176.01	176.01	117.34	88.00
TARGET # 2	2	2.00	.00	2.00	176.01	178.01	117.34	88.00
TARGET # 3	4	15.00	.00	15.00	173.26	188.26	115.51	86.63
TARGET # 4	6	17.00	.00	17.00	173.26	190.26	115.51	86.63
TARGET # 5	8	30.00	.00	30.00	170.51	200.51	113.67	85.25
TARGET # 6	10	32.00	.00	32.00	170.51	202.51	113.67	85.25
TARGET # 7	12	45.00	176.01	45.00	167.76	212.76	111.84	83.88
TARGET # 8	14	47.00	178.01	47.00	167.76	214.76	111.84	83.88
TARGET # 9	16	60.00	188.26	60.00	165.01	225.01	110.01	82.50
TARGET # 10	18	[illegible].00	190.26	62.00	165.01	227.01	110.01	82.50
TARGET # 11	20	75.00	200.51	75.00	162.26	237.26	108.17	81.13
TARGET # 12	22	77.00	202.51	77.00	162.26	239.26	108.17	81.13
TARGET # 13	24	90.00	212.76	90.00	159.51	249.51	106.34	79.75
TARGET # 14	26	92.00	214.76	92.00	159.51	251.51	106.34	79.75
TARGET # 15	28	105.00	225.01	105.00	156.76	261.76	104.51	78.38
TARGET # 16	30	107.00	227.01	107.00	156.76	263.76	104.51	78.38
TARGET # 17	32	120.00	237.26	120.00	154.01	274.01	102.67	77.00
TARGET # 18	34	122.00	239.26	122.00	154.01	276.01	102.67	77.00
TARGET # 19	36	135.00	249.51	135.00	151.26	286.26	100.84	75.63
TARGET # 20	38	137.00	251.51	137.00	151.26	288.26	100.84	75.63
TARGET # 21	40	150.00	261.76	150.00	148.51	298.51	99.01	74.25
TARGET # 22	42	152.00	263.76	152.00	148.51	300.51	99.01	74.25
TARGET # 23	44	165.00	274.01	165.00	145.76	310.76	97.17	72.88
TARGET # 24	46	167.00	276.01	167.00	145.76	312.76	97.17	72.88
TARGET # 25	48	180.00	286.26	180.00	143.01	323.01	95.34	71.50
TARGET # 26	50	182.00	288.26	182.00	143.01	325.01	95.34	71.50
TARGET # 27	52	195.00	298.51	195.00	140.26	335.26	93.51	70.13
TARGET # 28	54	197.00	300.51	197.00	140.26	337.26	93.51	70.13
TARGET # 29	56	210.00	310.76	210.00	137.51	347.51	91.67	68.75
TARGET # 30	58	212.00	312.76	212.00	137.51	349.51	91.67	68.75
TARGET # 31	2	225.00	323.01	235.33	117.68	353.01	78.45	58.84
TARGET # 32	4	227.00	325.01	237.33	117.68	355.01	78.45	58.84
TARGET # 33	6	250.33	335.26	250.33	114.93	365.26	76.62	57.46
TARGET # 34	8	252.33	337.26	252.33	114.93	367.26	76.62	57.46
TARGET # 35	10	265.33	347.51	265.33	112.18	377.51	74.78	56.09
TARGET # 36	12	267.33	349.51	267.33	112.18	379.51	74.78	56.09
TARGET # 37	14	280.33	353.01	280.33	109.43	389.76	72.95	54.71
TARGET # 38	16	282.33	355.01	282.33	109.43	391.76	72.95	54.71
TARGET # 39	18	295.33	365.26	295.33	106.68	402.01	71.12	53.34
TARGET # 40	20	297.33	367.26	297.33	106.68	404.01	71.12	53.34
TARGET # 41	22	310.33	377.51	310.33	103.93	414.26	69.28	51.96
TARGET # 42	24	312.33	379.51	312.33	103.93	416.26	69.28	51.96
TARGET # 43	26	325.33	389.76	325.33	101.18	426.51	67.45	50.59
TARGET # 44	28	327.33	391.76	327.33	101.18	428.51	67.45	50.59
TARGET # 45	30	340.33	402.01	340.33	98.43	438.76	65.62	49.21
TARGET # 46	32	342.33	404.01	342.33	98.43	440.76	65.62	49.21
TARGET # 47	34	355.33	414.26	355.33	95.68	451.01	63.78	47.84
TARGET # 48	36	357.33	416.26	357.33	95.68	453.01	63.78	47.84
TARGET # 49	38	370.33	426.51	370.33	92.93	463.26	61.95	46.46
TARGET # 50	40	372.33	428.51	372.33	92.93	465.26	61.95	46.46
TARGET # 51	42	385.33	438.76	385.33	90.18	475.51	60.12	45.09
TARGET # 52	44	387.33	440.76	387.33	90.18	477.51	60.12	45.09
TARGET # 53	46	400.33	451.01	400.33	87.43	487.76	58.28	43.71
TARGET # 54	48	402.33	453.01	402.33	87.43	489.76	58.28	43.71

TARGET # 55	50	415.33	463.26	415.33	84.68	500.01	56.45	42.34
TARGET # 56	52	417.33	465.26	417.33	84.68	502.01	56.45	42.34
TARGET # 57	54	430.33	475.51	430.33	81.93	512.26	54.62	40.96
TARGET # 58	56	432.33	477.51	432.33	81.93	514.26	54.62	40.96
TARGET # 59	58	445.33	487.76	445.33	79.18	524.51	52.78	39.59
TARGET # 60	60	447.33	489.76	447.33	79.18	526.51	52.78	39.59

INPUT DATA

SAM SPEED, (NM/MIN)	30		
TARGET SPEED	10		
LAUNCHER CYCLE TIME	7.50	ATTACKING AIRCRAFT	30
ILLUMINATION (SEC.)	30		
TARGET SPACING (SEC.)	2	ASCM LAUNCH RANGE	30
SAM'S PER SALVO	1	ASCM SPEED	20
MAX SAM'S AIRBORNE	24		
SEARCH RADAR HEIGHT	5000	NUMBER OF ASCM's	60
TARGET HEIGHT (FT.)	25		
HORIZION RANGE (NM)	94.22	note: AIRSHIP (6 ILLUM.), LINKED WITH 2 NTU ESCORTS (CG-16)	
DETECTION DELAY (SEC)	30		
OPEN FIRE RANGE	89.22		

TIME TARGET AT OPEN FIRE RANGE:		LAUNCHER READY	ILLUMINATOR FREE	LAUNCH TIME	TIME OF FLIGHT	TIME OF INTERCEPT	RANGE LAUNCH	RANGE @ INTERCEPT
TARGET # 1	0	.00	.00	.00	133.83	133.83	89.22	66.92
TARGET # 2	2	2.00	.00	2.00	133.83	135.83	89.22	66.92
TARGET # 3	4	7.50	.00	7.50	132.96	140.46	88.64	66.48
TARGET # 4	6	9.50	.00	9.50	132.96	142.46	88.64	66.48
TARGET # 5	8	15.00	.00	15.00	132.08	147.08	88.06	66.04
TARGET # 6	10	17.00	.00	17.00	132.08	149.08	88.06	66.04
TARGET # 7	12	22.50	133.83	36.00	127.83	163.83	85.22	63.92
TARGET # 8	14	24.50	135.83	38.00	127.83	165.83	85.22	63.92
TARGET # 9	16	43.50	140.46	43.50	126.96	170.46	84.64	63.48
TARGET # 10	18	45.50	142.46	45.50	126.96	172.46	84.64	63.48
TARGET # 11	20	51.00	147.08	51.00	126.08	177.08	84.06	63.04
TARGET # 12	22	53.00	149.08	53.00	126.08	179.08	84.06	63.04
TARGET # 13	24	58.50	163.83	72.00	121.83	193.83	81.22	60.92
TARGET # 14	26	60.50	165.83	74.00	121.83	195.83	81.22	60.92
TARGET # 15	28	79.50	170.46	79.50	120.96	200.46	80.64	60.48
TARGET # 16	30	81.50	172.46	81.50	120.96	202.46	80.64	60.48
TARGET # 17	32	87.00	177.08	87.00	120.08	207.08	80.06	60.04
TARGET # 18	34	89.00	179.08	89.00	120.08	209.08	80.06	60.04
TARGET # 19	36	94.50	193.83	108.00	115.83	223.83	77.22	57.92
TARGET # 20	38	96.50	195.83	110.00	115.83	225.83	77.22	57.92
TARGET # 21	40	115.50	200.46	115.50	114.96	230.46	76.64	57.48
TARGET # 22	42	117.50	202.46	117.50	114.96	232.46	76.64	57.48
TARGET # 23	44	123.00	207.00	123.00	114.08	237.08	76.06	57.04
TARGET # 24	46	125.00	209.08	125.00	114.08	239.08	76.06	57.04
TARGET # 25	48	130.50	223.83	144.00	109.83	253.83	73.22	54.92
TARGET # 26	50	132.50	225.83	146.00	109.83	255.83	73.22	54.92
TARGET # 27	52	151.50	230.46	151.50	108.96	260.46	72.64	54.48
TARGET # 28	54	153.50	232.46	153.50	108.96	262.46	72.64	54.48
TARGET # 29	56	159.00	237.08	159.00	108.08	267.08	72.06	54.04
TARGET # 30	58	161.00	239.08	161.00	108.08	269.08	72.06	54.04
TARGET # 31	2	166.50	253.83	199.33	84.50	283.83	56.33	42.25
TARGET # 32	4	168.50	255.83	201.33	84.50	285.83	56.33	42.25
TARGET # 33	6	206.83	260.46	206.83	83.63	290.46	55.75	41.81
TARGET # 34	8	208.83	262.46	208.83	83.63	292.46	55.75	41.81
TARGET # 35	10	214.33	267.08	214.33	82.75	297.08	55.17	41.38
TARGET # 36	12	216.33	269.08	216.33	82.75	299.08	55.17	41.38
TARGET # 37	14	221.83	283.83	235.33	78.50	313.83	52.33	39.25
TARGET # 38	16	223.83	285.83	237.33	78.50	315.83	52.33	39.25
TARGET # 39	18	242.83	290.46	242.83	77.63	320.46	51.75	38.81
TARGET # 40	20	244.83	292.46	244.83	77.63	322.46	51.75	38.81
TARGET # 41	22	250.33	297.08	250.33	76.75	327.08	51.17	38.38
TARGET # 42	24	252.33	299.08	252.33	76.75	329.08	51.17	38.38
TARGET # 43	26	257.83	313.83	271.33	72.50	343.83	48.33	36.25
TARGET # 44	28	259.83	315.83	273.33	72.50	345.83	48.33	36.25

TARGET # 45	30	278.83	320.46	278.83	71.63	350.46	47.75	35.81
TARGET # 46	32	280.83	322.46	280.83	71.63	352.46	47.75	35.81
TARGET # 47	34	286.33	327.08	286.33	70.75	357.08	47.17	35.38
TARGET # 48	36	288.33	329.08	288.33	70.75	359.08	47.17	35.38
TARGET # 49	38	293.83	343.83	307.33	66.50	373.83	44.33	33.25
TARGET # 50	40	295.83	345.83	309.33	66.50	375.83	44.33	33.25
TARGET # 51	42	314.83	350.46	314.83	65.63	380.46	43.75	32.81
TARGET # 52	44	316.83	352.46	316.83	65.63	382.46	43.75	32.81
TARGET # 53	46	322.33	357.08	322.33	64.75	387.08	43.17	32.38
TARGET # 54	48	324.33	359.08	324.33	64.75	389.08	43.17	32.38
TARGET # 55	50	329.83	373.83	343.33	60.50	403.83	40.33	30.25
TARGET # 56	52	331.83	375.83	345.33	60.50	405.83	40.33	30.25
TARGET # 57	54	350.83	380.46	350.33	59.63	410.46	39.75	29.81
TARGET # 58	56	352.83	382.46	352.83	59.63	412.46	39.75	29.81
TARGET # 59	58	358.33	387.08	358.33	58.75	417.08	39.17	29.38
TARGET # 60	60	360.33	389.08	360.33	58.75	419.08	39.17	29.38

APPENDIX B

SUPPLEMENTAL CALCULATIONS, TABLES AND FIGURES

A. Depth Of Fire Calculations

To generate the DOF contours in this paper, the basic firepower equations where taken from *NOA* [Ref. 22:pp. 230-233] and modified to account for low flying targets and fire control system limitations. The following assumptions hold:

a. both the ASCM velocity (V, in nm/sec) and height above water (H_M, in feet) are known.

b. the search radar height (H_R, in feet), SAM velocity (U), Fire Control System Delays (F_D) and the Damage Assesment Delay (T_D ,in seconds), are known.

Then, as in Figure 6:

R_H (nm), the radar horizon is found as: $(2H_R + 2H_M)^{1/2}$ (5280/6000)

F_R (nm), the range of the ASCM at the launching of the first SAM is found as:

$R_H - (F_D \times V)$

and the maximum effective range of the SAM, (R_X), is taken as F_R

$R_D = T_D \times V$, the distances traveled by the ASCM during a damage assesment delay

For an arbitray R_{CPA}:

a. The total path length of the ASCM through the engagement zone is:

$$P_L = cos^{-1} (R_{CPA} / R_X)$$

Given a closing Target,

The Target Angle is:

$$TA(1) = sin^{-1}(R_{CPA}/R_X)$$

The Lead Angle is:

$$LA(1) = sin^{-1} [(U\, sin\, (TA))/V]$$

The included angle between TA and LA is;

$$PHI = 180 - (TA + LA)$$

Then, by the law of sines:

$$R_I(1) = R_X \, sin\,(TA) \,/\, sin\,(PHI)$$

$$RT(1) = R_X \; sin\;(LA)/sin\,(PHI)$$

At the completion of the first intercept, if there is no time delay before the next SAM is launched and the target is still closing, then the new target and lead angles would be:

$$TA(2) = sin^{-1}(R_{CPA} / R_I(1))$$

$$LA(2) = (U \, sin\,(TA)) / V$$

Where $R_I(1)$ is substituted for R_X.

However, if there is a Damage assesment Delay, the value for $R_I(1)$ will no longer reflect the proper distance to the target at the instant of SAM launch and must be updated. A value, $R_{I'}$, is substituted for R_I. $R_{I'}$ is found using the following relationships. The the ASCMs distance from CPA at the end of the Damage Assesment delay is:

$$D_{CPA} = P_L/2 - [R_T(1) + R_D].$$

Thus the actual distance from the launching ship to the target at the end of the damage assesment delay, R_I', is found as:

$$R_I' = [(D_{CPA})^2 + (R_{CPA})^2]^{1/2}$$

Then the true target angle may be found as:

$$TA(2) = sin^{-1}(R_{CPA} / R_{I'})$$

Given an opening target:

$$TA(2) = 180 - sin^{-1}(R_{CPA} / R_{I'})$$

$$LA(2) = sin^{-1}((U \, cos\,(TA-90))/V)$$

PHI = 180 - (TA + LA)

Where D_{CPA} for opening targets is: $[R_T(1) + R_D]$

TABLE 18

PREDICTED VERSES ACTUAL AIRSHIP FIRST UNIT COSTS BY C.E.R.

AIRSHIP	ACTUAL	PREDICTED	% ERROR
AKRON	46.0	37.8	-21.8
MACON	31.0	37.8	17.9
GOODYEAR[1]	123.0	85.3	-44.1
ZPG-3W	25.0	27.2	8.2
XZSG-4	8.2	8.6	4.2
ZPG-1	18.6	18.1	-2.7
R-100	17.7	27.7	36.3
R-101	19.7	19.8	0.6
ZR-1	16.6	9.5	-73.9
LZ-127	10.9	18.0	39.4
LZ-129	31.3	28.5	-9.5
R-36	11.5	12.1	5.0
R-80	8.9	8.0	-10.7

Source, J.W. Noah [Ref. 28:p. 5] as supplied to OP-96V.

[1]Proposed Goodyear design never constructed, data point from Goodyear's projected cost verses JWN C.E.R.

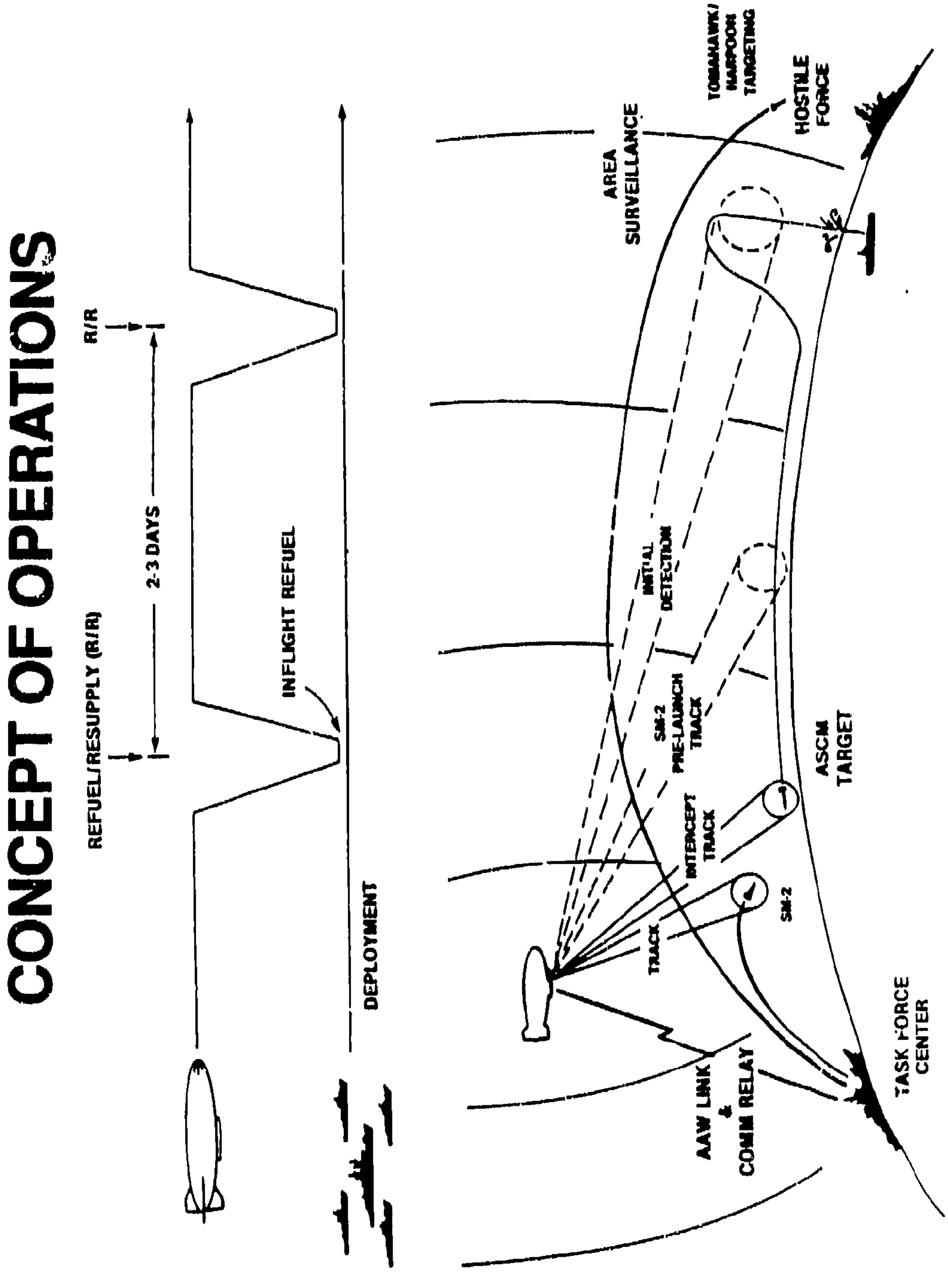

Figure 27. ODM Brief, August 1987, source NADC, page 1 of 4

CONCEPT OF OPERATIONS

- AIRSHIP DEPLOYS AS A SHIP
- REMAINS AT SEA FOR DURATION OF BATTLE GROUP DEPLOYMENT
- CONDUCTS PERIODIC IN-FLIGHT RESUPPLY
- ORGANIC BATTLE GROUP SURVEILLANCE ASSET
- MAINTAINS CONTINUOUS AIRBORNE STATION
- STATION AND MISSION FOCUS DIRECTED BY BATTLE GROUP COMMANDER

Figure 28. ODM Brief, August 1987, source NADC, page 2 of 4

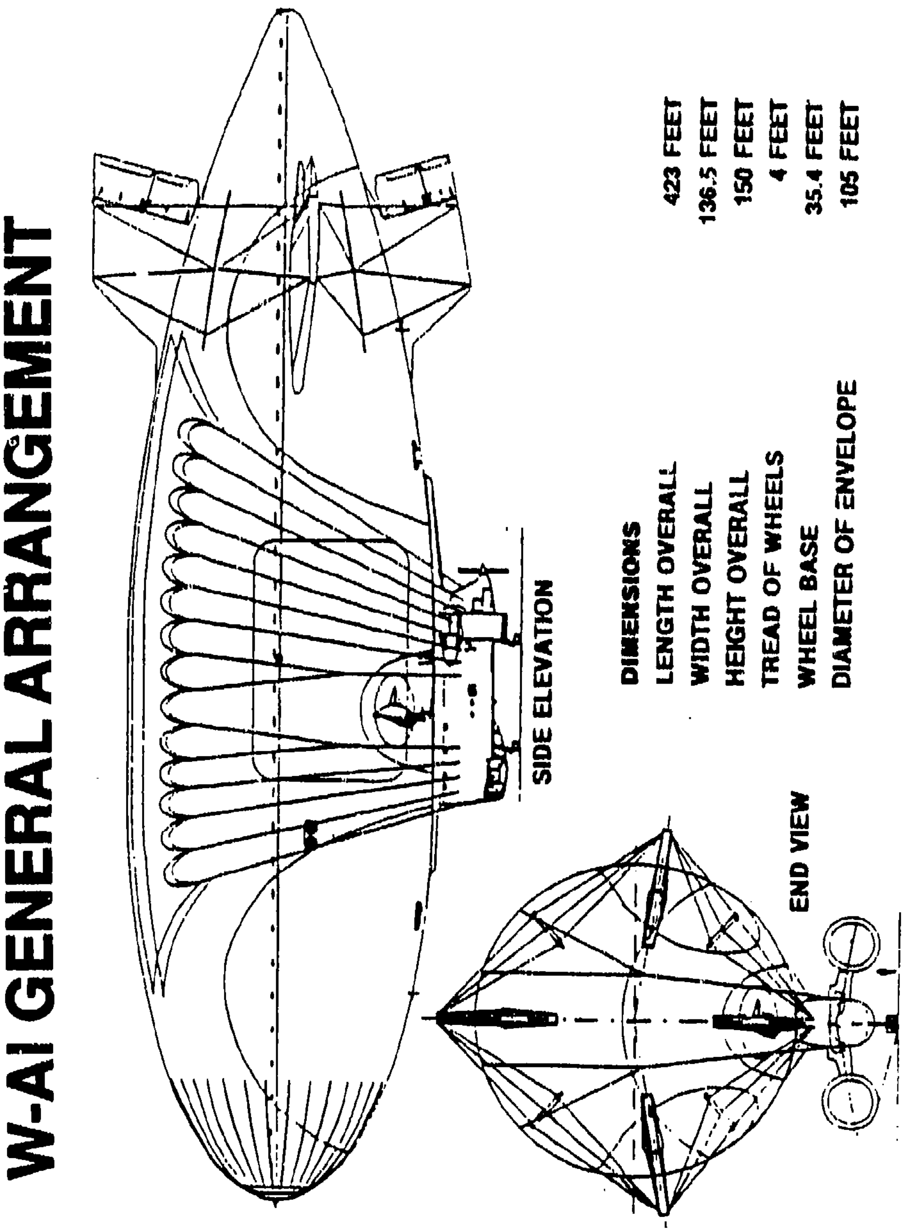

Figure 29. ODM Brief, August 1987, source NADC, page 3 of 4

CURRENT CONTRACT

- AWARDED TO W-AI 5 JUNE 1987
  - — FFP FOR $168,930,000
  - — VEHICLE AND E-2C MISSION AVIONICS
  - — FIRST FLIGHT NOVEMBER 1990
  - — WIDE APERTURE ANTENNA (10'X40')
- 5 OPTIONAL AIRSHIPS

Figure 30. ODM Brief, August 1987, source NADC, page 4 of 4

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